Analysis of Alternative Energy Options for Buildings

by
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Abstract

The importance of utilizing different types of energy and their technical application is discussed. Awareness around the globe about the world energy crisis and its critical environmental condition has put more emphasis on the use of renewable energies in every corner of life. It is a well-known fact that global warming, inefficient use of energy and greenhouse gases are damaging the environment, species and human life drastically. These issues will be discussed in recently conducted research.

To address the crucial state of our environment, two simultaneous scenarios are considered. Initially, energy conservation and the switch to a low carbon/no carbon fuel are studied. As for energy conservation in buildings, smart methods in the use of energy in buildings are discussed. Based on different research reported, humans must change their attitude toward the use of resources, and in particular, be conscientious about energy consumption. Next, renewable energy promises a suitable alternative to energy needs in this century, and the best means to overcome the environmental issue and energy crisis is discussed. The practical methods of calculation for solar technology equipment, ground source heat pumps, and wind turbines are explained. In the application part of the study, four buildings are chosen as case studies; two of them from residential sectors, one is a commercial/institutional building, and the fourth is an industrial building. A ground source heat pump for heating and cooling, a solar water heater for heating space or hot water, and a photovoltaic panel for generating electricity are designed for the case studies. Even projects under hybrid systems combined from two technologies are designed. 36 different energy options are calculated for the four case studies. Results show that if a target is reducing CO_2 emissions, what systems are the best. In contrast, when decision making is based on budget, what system is the first choice? Not only are technology, environmental protection and cost the main parameters for deciding on renewable technologies, but so are reliability, installation, maintenance and ease of use. Hence, renewable energy systems are categorized based on a broad vision.

Table of Contents

Acknowledgment i
Abstract iii
Table of Content iv
Figure Captions xi
Table Captions xvi
Nomenclature xvii

Chapter 1: Introduction

1.1. Humankind's Problem 1
1.1.1. Energy Crisis 1
1.1.2. Natural Resources Limitation 1
1.1.3. The Environment 1
1.2. Problem Consequences 2
1.2.1. Climate Change 3
1.2.2. Stratospheric Ozone Depletion 5
1.2.3. Acid Rain 5
1.3. Solutions 5
1.3.1. Renewable Energy 6
1.3.2. Hydrogen Energy 7
1.4. Efficient Energy Use 7
1.5. Energy in Canada 8
1.6. Emissions in Canada 11
1.7. Summary 12

Chapter 2: Motivation & Objectives

2.1. Motivation 12
2.2. Thesis Outline 12

Chapter 3: Literature Review

3.1. Introduction 15
3.2. Building Sector 15

3.3. Building Rating Schemes 16
3.4. Building Environmental Assessment 19
3.4.1. Leadership in Energy and Environmental Design (LEED) 19
3.4.2. Building Research Establishment Environmental Assessment Method (BREEAM) 22
3.4.3. The Hong Kong Building Environmental Assessment Method (HK-BEAM) 23
3.4.4. Comparison of LEED, BREEAM and HK-BEAM 24
3.5. Efficiency 25
3.5.1. Efficiency and Appliances 26
3.5.2. Efficiency in Large Scale 27
3.5.3. Efficient Power Plants 28
3.6. Perception of Renewable Energy 29
3.7. Summary 31
Chapter 4: Renewable Energy Systems
4.1. Introduction 33
4.2. Grid Dependency or Independency 33
4.2.1. Off Grid 33
4.2.2. Grid Tie 34
4.2.2.1 Grid Tie Without Batteries 35
4.2.2.2. Grid Tie With Batteries 37
4.2.2.3. Grid Tie Parallel With Batteries 37
4.3. Common Practices 39
4.3.1. Solar Water Heaters 39
4.3.1.1. Flat Solar Water Panels 39
4.3.1.2. Evacuated Tube Solar Water Panels 40
4.4. Photovoltaic (PV) Panels 43
4.4.1. PV Panel Efficiency 43
4.5. Wind Turbines 44
4.5.1. Horizontal Wind Turbines 45
4.5.2. Vertical Wind Turbines 46
4.6. Geothermal Power 47
4.6.1. The Heating Cycles 50

4.6.2. The Cooling Cycles ... 51
4.6.3. Efficiency in Geothermal Energy System ... 51
4.7. Comparison of Geothermal Energy to Wind and Solar Energy ... 52
4.8. Comparison of Wind Turbine and PV Panels ... 52
4.9. Summary ... 53

Chapter 5: Analysis of Renewable Energy Technology Systems

5.1. Introduction ... 54
5.2. PV Array Calculation Methods ... 54
5.2.1. Method 1 ... 54
5.2.2. Method 2 ... 55
5.3. Geothermal Energy System Calculations ... 56
5.3.1. Bin Method and Design Condition ... 56
5.3.2. Building Load Calculation – Descriptive Data Method ... 57
5.3.2.1. Transmission Losses (Conductive & Convective) ... 59
5.3.2.2. Solar Gains (Sensible) ... 60
5.3.2.3. Internal Gains (Sensible) ... 62
5.3.2.4. Fresh Air Load (Sensible) ... 62
5.3.2.5. Fresh Air Load (Latent) ... 63
5.3.2.6. Internal Gains (Latent) ... 64
5.3.3. Building Load Calculation – Energy Use Method ... 65
5.3.4. Building Load Calculation for each Temperature Bin ... 66
5.3.5. Earth Connection - Closed-Loop Ground Heat Exchangers ... 66
5.3.6. Heat Pump System ... 67
5.3.6.1. Coefficient of performance (COP) and capacity ($\boldsymbol{Qc/hQc/h}$) ... 67
5.3.6.2. Entering water temperature (Tw,i) for closed-loop ground exchanger ... 68
5.3.7. Energy Use Evaluation ... 69
5.3.7.1. Heat pump run time and energy use of backup pumps ... 69
5.3.7.2. Supplemental heating or cooling needs ... 69
5.4. Cost Analysis ... 70
5.5. Wind Turbine Calculation Method ... 70
5.6. Summary ... 71

Chapter 6: Case Studies

6.1. Introduction 72
6.2. Case Study #1 72
6.2.1. Using Solar Water Heaters 74
6.2.1.1. Energy Utilization 74
6.2.1.2 Emission Reduction 75
6.2.1.3. Cost 76
6.2.2. Using Photovoltaic Panels 78
6.2.2.1. Energy Utilization 79
6.2.2.2. Emission Reduction 80
6.2.2.3. Cost Analysis 81
6.2.3. Using Geothermal System 82
6.2.3.1. Energy Utilization 83
6.2.3.2. Emission Reduction 86
6.2.3.3. Cost Analysis 87
6.2.4. Hybrid System #1 88
6.2.4.1. Energy Utilization 89
6.2.4.2. Emission Reduction 90
6.2.4.3. Cost Analysis 91
6.2.5. Hybrid System #2 93
6.2.5.1. Energy Utilization 94
6.2.5.2. Emission Reduction 94
6.2.5.3. Cost Analysis 95
6.2.6. Hybrid System #3 97
6.2.6.1. Energy Utilization 97
6.2.6.2. Emission Reduction 98
6.2.6.3. Cost Analysis 98
6.3. Case Study #2 100
6.3.1. Using Solar Water Heaters 102
6.3.2. Using Photovoltaic Panels 102
6.3.2.1. Energy Utilization 103

6.3.2.2. Emission Reduction 103
6.3.2.3. Cost Analysis 104
6.3.3. Using the Geothermal System 105
6.3.4. Hybrid System #1 106
6.3.5. Hybrid System #2 107
6.3.5.1. Energy Utilization 107
6.3.5.2. Emission Reduction 108
6.3.5.3. Cost Analysis 108
6.3.6. Hybrid System #3 110
6.4. Case Study #3........ 111
6.4.1. Using Solar Water Heaters 113
6.4.1.1. Energy Utilization 114
6.4.1.2. Emission Reduction 114
6.4.1.3. Cost Analysis 115
6.4.2. Using Photovoltaic Panels 117
6.4.2.1. Energy Utilization 117
6.4.2.2. Emission Reduction 120
6.4.2.3. Cost Analysis 120
6.4.3. Using Geothermal System 122
6.4.4. Hybrid System #1 123
6.4.5. Hybrid System #2 124
6.4.5.1. Energy Utilization 124
6.4.5.2. Emission Reduction 124
6.4.5.3. Cost Analysis 125
6.5. Case Study #4 127
6.5.1. Using Solar Water Heaters 129
6.5.1.1. Energy Utilization 129
6.5.1.2. Emission Reduction 130
6.5.1.3. Cost Analysis 130
6.5.2. Using Photovoltaic Panels 132
6.5.2.1. Energy Utilization 133

6.5.2.2. Emission Reduction 134
6.5.2.3. Cost Analysis 135
6.5.3. Using the Geothermal System 137
6.5.4. Hybrid System #1 138
6.5.5. Hybrid System #2 138
6.5.5.1. Energy Utilization 139
6.5.5.2. Emission Reduction 139
6.5.5.3. Cost Analysis 140
6.6. Summary 142

Chapter 7: Results & Discussion

7.1. Introduction 143
7.2. Technologies Comparison 143
7.2.1. Case #1 Technology Comparison 144
7.2.1.1. Solar Energy Technology Comparison 144
7.2.1.2. Geothermal Energy and Solar Energy Comparison 144
7.2.1.3. Alternative Energy Options Comparison 145
7.2.2. Case #2 Technology Comparison 146
7.2.3. Case #3 Technology Comparison 147
7.2.4. Case #4 Technology Comparison 149
7.3. Environmental Comparison 151
7.3.1. Case #1 Environmental Comparison 152
7.3.2. Case #2 Environmental Comparison 152
7.3.3. Case #3 Environmental Comparison 153
7.3.4. Case #4 Environmental Comparison 154
7.4. Cost Comparison 155
7.4.1. Case #1 Cost Comparison 155
7.4.2. Case #2 Cost Comparison 156
7.4.3. Case #3 Cost Comparison 157
7.4.4. Case #4 Cost Comparison 158
7.5. Summary 159

Chapter8: Conclusions & Recommendation for Future Research

8.1. Conclusion 161

8.2. Recommendation for Future Research 161

References 163

Figures Captions

Figure 1-1: Energy resources in Canada 9
Figure 1-2: Energy consumption by sector in Canada 10
Figure 1-3: Energy consumption in residential sector 10
Figure 1-4: GHG Emission by sector in Canada 11
Figure 1-5: GHG Emission in residential sector in Canada 12
Figure 4-1: Off grid system basic design 35
Figure 4-2: Grid tie without batteries 36
Figure 4-3: Grid tie with batteries 37
Figure 4-4: Grid tie parallel with batteries 38
Figure 4-5: Flat solar panel 39
Figure 4-6: Tube solar panel 40
Figure 4-7: Tube solar panel's physics 41
Figure 4-8: Running a complete system with solar water heater 42
Figure 4-9: A PV panel, SCM series 215W 43
Figure 4-10: Seasonal tilt of the solar array 44
Figure 4-11-A: A typical vertical wind turbine 45
Figure 4-11-B: A typical horizontal wind turbine 45
Figure 4-12: A Schematic from Zephyr blade design for vertical wind turbine 47
Figure 4-13: A schematic from conical blade design for vertical wind turbine 47
Figure 4-14: A view from a geothermal unit with main inside components 49
Figure 4-15: A schematic picture of the ground source heat pump in heating cycle 51
Figure 6-1: Electricity consumption for the household in case #1 73
Figure 6-2: Electricity usage distribution for case #1 73
Figure 6-3: Natural Gas Consumption in case #1 74
Figure 6-4: Layout of energy resources for case #1, when using solar thermal 74
Figure 6-5: CO_2 reduction by solar heater panels for case #1 75

Figure 6-6: Cost summary for solar heater panels by considering Governmental rebate for case#1 77
Figure 6-7: Cost summary of solar heater panels without Governmental rebate for case #1 78
Figure 6-8: Layout of energy resources for case #1, when using solar electricity 78
Figure 6-9: CO_2 reduction by PV panels for case #1 80
Figure 6-10: Cost summary of PV solar panels with Governmental rebate for case #1 81
Figure 6-11: Cost summary of PV solar panels without Governmental rebate for case #1 82
Figure 6-12: Layout of energy resources for case #1, when using geothermal energy 83
Figure 6-13: RETScreen results for Case #1 85
Figure 6-14: RETScreen results for Case #1 85
Figure 6-15: Emission reduction by using geothermal system for case #1 86
Figure 6-16: Cost analysis for geothermal system, with Governmental rebate for case#1 87
Figure 6-17: Cost analysis of geothermal system without Governmental rebate for Case #1 88
Figure 6-18: Layout of energy resources for case #1, when using hybrid system #1 89
Figure 6-19: Emission reduction by geothermal system for case #1 91
Figure 6-20: Cost analysis of hybrid system with Governmental rebate for case #1 92
Figure 6-21: Cost analysis of hybrid system#1 without Governmental rebate for Case #1 93
Figure 6-22: Layout of energy resources for case #1, when using hybrid system #2 93
Figure 6-23: CO_2 reduction by hybrid system #2 for case #1 94
Figure 6-24: The summary of financial balance for hybrid system #2 with governmental rebate for sase #1 96
Figure 6-25: The summary of financial balance for hybrid system #2 without governmental rebate for case #1 96
Figure 6-26: Layout of energy resources for case #1, when using hybrid system #3 97
Figure 6-27: CO_2 reduction by hybrid system #3 for case #1 98
Figure 6-28: The summary of financial balance for hybrid system #3 with governmental rebate for case #1 99

Figure 6-29: The summary of financial balance for hybrid system #3 without governmental rebate for case #1 100
Figure 6-30: Average daily electricity consumption in case #2 101
Figure 6-31: Natural gas consumption in household case #2 101
Figure 6-32: Layout of energy resources for case #2, when using solar thermal energy 102
Figure 6-33: Layout of energy resources for case #2, when using solar electricity 102
Figure 6-34: CO_2 reduction in PV panels' life for Case #2 104
Figure 6-35: Cost summary of PV solar panels' life with Governmental rebate for case #2 105
Figure 6-36: Cost summary of PV solar panels without Governmental rebate for case #2 105
Figure 6-37: Layout of energy resources for case #2, when using geothermal energy 106
Figure 6-38: Layout of energy resources for case #2, when using hybrid system #1 107
Figure 6-39: Layout of energy resources for case #2, when using hybrid system #2 107
Figure 6-40: CO_2 reduction by hybrid system #2 for case #2 108
Figure 6-41: The summary of financial balance for hybrid system #2 with governmental rebate for case #2 110
Figure 6-42: The summary of financial balance for hybrid system #2 without governmental rebate for case #2 111
Figure 6-43: Layout of energy resources for case #2, when using hybrid system #3 111
Figure 6-44: Electricity usage distribution in case #3 112
Figure 6-45: Natural gas Consumption in Brampton Library, Case #3 113
Figure 6-46: Electricity Consumption in Brampton Library, Case #3 113
Figure 6-47: Layout of energy resources for case #3, when using solar thermal energy 114
Figure 6-48: CO_2 reduction by solar panel for case #3 115
Figure 6-49: Cost summary by solar collector panels with Governmental rebate for case # 3 116
Figure 6-50: Cost summary by solar collector panels without Governmental rebate for case # 3 117

Figure 6-51: Layout of energy resources for case #3, when using solar electricity 117
Figure 6-52: Placing 10 modules in one mount 118
Figure 6-53: Dimensions on a mount. Blue area is considered for maintenance needs 118
Figure 6-54: Layout of mounts on the roof of the library 119
Figure 6-55: CO_2 reduction in by solar panels for Case # 3 120
Figure 6-56: Cost summary by PV solar panels with Governmental rebate for case #3 121
Figure 6-58: Layout of energy resources for case #3, when using geothermal energy 122
Figure 6-59: Layout of energy resources for case #3, when using hybrid system #1 123
Figure 6-60: Layout of energy resources for case #3, when using hybrid system #2 124
Figure 6-61: CO_2 reduction by hybrid system #2 for case #3 125
Figure 6-62: The summary of financial balance for hybrid system #2 with governmental rebate for case #3 126
Figure 6-63: The summary of financial balance for hybrid system #2 without governmental rebate for case #3 127
Figure 6-64: Electricity consumption in injection plastic company, Case #4 128
Figure 6-65: Electricity usage distribution for case #4 129
Figure 6-66: Layout of energy resources for case #4, when using solar thermal energy 130
Figure 6-67: CO_2 reduction in 25 years solar panels' life, Case #4 131
Figure 6-68: Cost summary by solar heater panels with Governmental rebate for case #4 132
Figure 6-69: Cost summary by solar heater panels without Governmental rebate for case #4 133
Figure 6-70: Layout of energy resources for case #4, when using solar electricity 134
Figure 6-71: The configuration of the PV modules on the roof of the injection plastic company. Case #4 135
Figure 6-72: CO_2 reduction by years PV panels for case #4 136
Figure 6-73: Cost summary by PV panels with Governmental rebate for case #4 136
Figure 6-74: Cost summary by PV panels without Governmental rebate for case #4 137
Figure 6-75: Layout of energy resources for case #4, when using geothermal energy 137

Figure 6-76: Layout of energy resources for case #4, when using hybrid system #1 138
Figure 6-77: Layout of energy resources for case #4, when using hybrid system #2 139
Figure 6-78: CO_2 reduction by hybrid system #2 for case #4 140
Figure 6-79: The summary of financial balance for hybrid system #2 with governmental rebate for case #4 141
Figure 6-80: The summary of financial balance for hybrid system #2 without governmental rebate for case #4 141
Figure 7-1: Prioritized options from point of technology view for case #1 146
Figure 7-2: Prioritized options from point of technology view for case #2 147
Figure 7-3: Prioritized options from point of technology view for case #3 148
Figure 7-4: Prioritized options from point of technology view for case #4 149
Figure 7-5: Prioritized options from point of environmental view for case #1 152
Figure 7-6: Prioritized options from point of environmental view for case #2 153
Figure 7-7: Prioritized options from point of environmental view for case #3 154
Figure 7-8: Prioritized options from point of environmental view for case #4 154
Figure 7-9: Prioritized options from point of financial view, case #1 156
Figure 7-10: Prioritized options from point of financial view, case #2 157
Figure 7-11: Prioritized options from point of financial view, case #3 158
Figure 7-12: Prioritized options from point of financial view, case #4 159

List of Tables

Table 3-1: LEED point system requirements 20

Table 3-2: General Comparison (Burrnet and Lee, 2008) 24

Table 3-3: Baseline energy use (Burrnet and Lee, 2008) 25

Table 6-1: Ground Source heat pump for case #1 84

Table 7-1: Technology Summaries for four case studies 143

Table 7-2: Environmental effect Summaries for four cases 151

Table 7-3: Cost Summaries for four cases 155

Table 7-4: All Summaries for four cases 160

Nomenclature

A_s = Annual surface temperature [°C]

C_P = Specific heat [kJ/kg)°C]

D = Air density [kg/m^3]

f = Fraction of latent to sensible load

E_k = Kinetic energy [J]

i = Monthly interest rate [%]

IR = inflation rate [%]

k = Thermal conductivity [W/m °C]

k_i = Correlation coefficient

M = Mass [kg]

M = Monthly payment [$]

M = Solar heat gain interpolation coefficient [J/°C]

N = number of monthly payments

n = year

P = Power [W]

P = Principal of the investment [$]

q = Heat load [J]

Q_c = Heat pump cooling capacity [J]

Q_h = Heat pump heating capacity [J]

S = Floor area [m^2]

S = Swept area [m^2]

T = Time [s]

$\overline{T}_g$ = Annual average surface soil temperature [°C]

V = Velocity [m/s]

$\dot{V}$ = Volumetric flow rate of incoming air [m^3/s]

X_s = Depth of the soil [m]

$Y0$ = Dollar value [$]

Yn = Future Dollar value in year n [$]

Z = Number of floors

ρ = Density [kg/m^3]

λ_i = Correlation coefficient

Acronyms

BE2EAM = Building Energy and Environmental Assessment Method

BRE = Building Research Establishment

BREEAM = Building Research Establishment Environmental Assessment Method

COP_c = *C*ooling Coefficient of Performance

COP_h = Heating Coefficient of Performance

CHP = Combined Heat & Power

COP = Coefficient of Performance

EWT = Least design incoming Water Temperature

GHG = Greenhouse Gas emissions

HK-BEAM = Hong Kong Building Environmental assessment Method

IAQ = Indoor Air Quality

LEED = Leadership in Energy and Environmental Design

ORME = Office Rating Methodology

PV = Photovoltaic

ROI = Return of Investment

USGBC = US Green building Council

Chapter 1: Introduction

1.1. Humankind's Problem

The modern world is in crisis. Many of the problems are localized and affect certain groups of people. Even if humankind could forget these differences and unite as a modern civilized society, three critical dilemmas would remain. Resolving these issues demands smart and fast solutions from all individuals, if the world is to overcome the predicaments detailed in the following paragraphs.

1.1.1. Energy Crisis

The cost of energy is dependent on political rather than natural events and is one of the major features of every economy. Energy prices have experienced sharp fluctuations since the 1970s. Even in the present decade we have been witness to soaring energy costs. Each time it has had a deep effect on the global economy as energy prices have an influence on every product and service used in daily life.

1.1.2. Natural Resources Limitation

Even if humankind denies that other problems exist, it should believe fossil fuels are limited because of wasting energy over the past century, and that soon these resources will run out. Before that happens, humans must find or create new fuels and develop the technology to use them. This will take time and money for research and development, and extensive effort to bring them up to practical production levels. Hence, the sooner serious work begins the better.

1.1.3. The Environment

The earth has existed for approximately 4.5 billion years, during which time it has supported millions of species. Humans have survived for thousands of years from the Stone Age to the computer age, but technological enhancement in this century has been drastically destroying the environment. Earth is crying out for help through climate change, air pollution, acid rain, and stratospheric ozone depletion. High rates of cancer and heart attacks reflect the malfunction on earth which is passed to humankind. Our earth is in need of urgent help, otherwise earth will not be the planet of life.

1.2. Problem Consequences

Humankind started the industrial age proudly by inventing different kinds of machines for transportation, farming, manufacturing and construction. Man continues to invent new machines, equipment and instruments. Man arrogantly uses his own creations without considering the consequences. Dincer (2000) cited that humankind has created environmental problems, and since human population, consumption and energy needs increase, environmental issues are rapidly increasing, too. Over-use of resources was a stylish attitude in the 1950s. In that era, the Saskatoon Electricity Facility was built without considering any switches for turning off the lights! The problem rose in the summer, when cooling systems could not take the extra heat load by lights. Gradually, considering consumption came to engineering consideration in the designing stage. And, in the first decade of the twenty-first century, energy conservation is the most important parameter in design. It is definitely time for another revolution against the industrial revolution. This transformation is due to facing the consequences of abusing resources during the last century. It is time to consider renewable energies more seriously, as a result of greenhouse gases' (GHG) effects on the environment, and a limited supply of conventional energy resources (fossil fuels) (IPCC, 2001). While replacing renewable energy with non-renewable energy, methods of reducing energy consumption should also be considered. Using energy effectively is a very important subject to study. Dincer (2000) reported that the crisis with energy supply is not limited to global warming, air pollution, acid rain, ozone reduction, forest damage and emission of radioactive substances; there are other critical problems, and these issues should be resolved urgently and simultaneously if civilization is planning to have a victorious energy future with the least detrimental environmental effects.

With respect to environmental issues regarding the inefficient use of energy, climate change, stratospheric ozone depletion and acid rain are the most crucial dilemmas, and are explained in the following paragraphs:

1.2.1. Climate Change

One of the major consequences of abusing energy resources is an increase in climatic temperature. Dincer (2000) mentioned that the major environmental issue caused by energy use is the greenhouse effect, also known as global warming. Bradley et al. (1991) suggest the main cause is emissions which devastate the environment. Dincer (2000) also stated in the same paper that by increasing greenhouse gases, heat radiating from the earth's surface traps more in the atmosphere and apparently the temperature of the earth increases. Colombo (1992) quoted by increasing the earth's temperature 0.6 degree Celsius in the last century, the sea level has risen by approximately 20 cm. It has had a significant impact on the environment including water, air, plants, animals and humans. The Intergovernmental Panel for Climate Change forecasted the average temperature would rise 1.4 – 5.8 degrees Celsius before the end of the 21st century (IPCC, 2001). Colombo (1992) estimated that by this much of an increase in the temperature of the earth's surface, potentially sea levels would increase 30 to 60 cm in the 21st century. The root cause of this temperature change is energy use for heating and cooling buildings. Separately, in 1995, research was conducted in different parts of the world to find methods to slow down global warming. Belzer used the degree-days method to estimate the variation of energy in commercial buildings based on climate changes. Chow and Levermore (2004) suggested a plan to evaluate the climate change effect on thermal comfort using the dry resultant temperature method in the UK. Gaterell and McEvoy (2005) used TAS software in different scenarios to calculate the reduction of heating energy by 17% - 72% in residential buildings in the UK by 2050. The Chinese government has targeted shrinking China's energy consumption by 20% by 2010**,** Yang (2008). Tachter (2006) calculated the peak change in local electrical demand between -2.1% - 4% simply changed the climate an average of 1 degree Celsius. The Tacher methodology was a linear regression model based on an Australian model. Mirasagedis (2007) used a multi-regression model to develop, from data over an eleven year period, predictions of the effect of several climatic plus socio-economic factors on potential demand of electricity in Greece. Based on this study, by climate change, the demand for electricity was estimated to increase 3.6% - 5.5% annually. The European Union proposed to save the earth from climate change jeopardy. 2.0 degrees Celsius is the limit for global warming, Bow and Anderson (2007) Honnery et al. (2008) stated that in order to prevent the dangers of climate change, emissions must be reduced rapidly and on a large scale, as part of the technical solution, energy efficiency should improve,, and renewable and nuclear energy and low carbon fuel must be promoted.

In Switzerland, Imboden, Kost and Siller (2007) proposed, in different scenarios, methods of reduction in energy consumption by a factor of 3, and a decrease in CO_2 emissions by a factor of 5 before year 2050 in residential buildings. The methods showed the successful strategy in cutting specific heat demand of live buildings during the renovation and replacing the heating and hot water systems by less carbon intensive fuel. Now, the global average use of energy is 2100 W/capita. The minimum is 300 W/capita (Bangladesh) and the maximum is 10,000 W/capita (US and Canada). Imboden and Roggo (2000), Steger et al. (2002), Jochem (2004), Spreng (2005), each suggested an industrial country like Switzerland would be able to cover its energy demands with 2000 W/capita instead of its present 6000 W/capita. The Board of the Swiss Federal Institute of Technology promoted the concept of “2000 Watt Society” in ETH-Rat (1998). The Swiss Federal Council considered “2000 Watt Society” as part of a “Sustainable Development Strategy”. Therefore, the Federal Energy Research Commission’s (CORE) goal for an energy and climate protection policy was having a “Sustainable Development Strategy” (2004). In other words, Switzerland should reduce present energy consumption per capita by a factor of 3 in the next 45 years.

Renaud and Zmeureanu (2008) conducted a case study of a house to estimate the potential climate change on energy consumption for heating existing houses. The method was applied to eleven other houses and the reduction of energy was 7.9% - 16.9% based on climate change between 1961 to 1990 and the future period of 2040-2069. The methodology used historical energy consumption data. The study was conducted in

Canada (Montreal), and was the extension of Zmeureanu's previous studies (1990, 1992) on estimation of climate change impact on annual heating energy consumption in houses.

1.2.2. Stratospheric Ozone Depletion

Ozone is the layer with a thickness of 12 to 25 km around the earth which protects the earth by absorbing the ultraviolet (UV) radiation and infrared radiation from the sun (Dincer, 1998). With depletion of the ozone layer, ultraviolet radiation reaches the earth at more than safe, acceptable levels, thereby causing an increase in eye damage, skin cancer and other troubles to humans and animals (Dincer, 2000). NOx, produced by combustion engines using fossil fuel and biomass fuel, CFCs, used in refrigeration and air conditioning equipment, insulation foam, nitrogen fertilization, natural gentrification and aircrafts are the main contributors in reduction of the ozone layer (Dincer, 2000).

1.2.3. Acid Rain

Dincer (2000) quoted acid precipitation as a form of pollution resulting from combustion of fossil fuels in stationary or mobile engines, NOx and SO_2, which converts to acids like sulphuric and nitric. Dincer (2000) also mentioned electric power generation, residential heating and industrial consumption of energy are the major sources of acid precipitation. The main responsibility of these energy related problems belongs to the U.S., countries from the former Soviet Union, and China (Anon, 1995).

1.3. Solutions

Humankind is at the phase which is so very dependent on the modern lifestyle. Man of the new century cannot survive without his own created technology. Thus, he should come up with new practical ideas to replace the energy system. The practical solutions come from the problems. The new energy system should cover the following aspects:

- Being independent from political situations in any part of the world;
- Not contributing to environmental problems;
- Having endless resources;

- Being accessible for everyone and everywhere; and
- Being affordable for everyone and everywhere

1.3.1. Renewable Energy

Dincer and Midilli (2008) state energy is the major interface between nature and humans, and is an important factor in economic development. Energy resources are necessary to fulfil human needs and enhance life quality, but the side effects of this energy consumption are affecting the environment (Dincer et al., 2008). In this regard, the United Nations obligated the energy sector to follow effective atmosphere-protection strategies to boost efficiency and transition to environmentally friendly energy systems Strong (1992). Improving efficiency directly decreases CO_2 emissions, and this can be reached by cutbacks in the use of fossil fuels and replacing them with alternative energy resources (Dincer et al., 2008). Fossil fuels are used for generating heat and power in today's world, and are an enormous danger to global sustainability and stability. The problem has a snowball effect by boosting population, improving technology and consequently increasing energy demand (Dincer and Midilli, 2008). Dincer and Midilli (2007) explained that globally the world cannot use fossil fuels any longer; sustainable energy must urgently take their place. McGowan (1990) cites renewable energy sources and systems are capable of affecting the following technical, environmental, economical and political issues:

- crucial environmental issues (green house, stratospheric ozone layer, acid rain);
- environmental disgrace;
- running down of the world's conventional energy sources; and
- boosting energy consumption in developing countries.

Hartly (1990) mentions renewable energy techniques can make marketable energy by transforming natural phenomena into practical energy. Therefore, renewable energy systems are the most efficient and effective solutions. This is the reason for the strong bond between renewable energy and sustainable development (Dincer, 2000). Renewable energy is categorized as:

1. geothermal energy;
2. biomass energy;
3. hydro energy;
4. solar energy; and
5. wind energy.

1.3.2. Hydrogen Energy

Hydrogen is another alternative energy for fossil fuels. Wide research and development are conducted on hydrogen energy, fuel cells and related subjects. Some advantages of hydrogen energy are as follows:

- it is environmentally friendly; production and utilization of hydrogen is a potential solution in urgently reducing global warming (Dincer et al., 2007)

- hydrogen is very efficient in power generation because it is exegetically efficient (Kyritsis and Rakopoloulos, 2006).

1.4. Efficient Energy Use

Solutions to humankind problems are not limited to a new energy system. Part of this solution is modifying energy consumption. It means developing new methods of using energy while not significantly changing one's lifestyle. In other words, using energy effectively should be considered seriously. Resolving the original problem is not only producing energy with natural renewable resources, but also using energy wisely. These two sides should work together to find the final solution. Smart use of energy should be applied in building the buildings initially or should be considered at renovation time. For example, running dishwashers with full loads and or programming the air-dry option is a savvy method of using dishwashers.

Energy use can also be defined in different buildings like farms, industrial buildings, or residential buildings.

1.5. Energy in Canada

Canada is a country rich in resources and in its variety of energy resources. According to Statistics Canada (2002), Canada is a gigantic energy consumer, almost equal to the USA (USA = 0.34 capita), and number one in the G-8 nations. The reason why Canada is high in energy consumption lies in the following facts:

- long travel distance;
- long, bitterly cold winters; and
- an economy based on high energy use industries like mining, forestry petrochemical, pulp and paper, aluminum smelters, refining and steel manufacturing.

Figure 1-1 depicts energy resources in Canada. It shows that the three main resources of energy are electricity, natural gas and motor gasoline. All these resources are high in producing GHG (greenhouse gas emissions), considering that burning fossil fuel mostly produces electricity. In other words, Canada contributes directly to producing GHG emissions by generating energy.

According to the Kyoto Protocol, Canada must reduce energy consumption with fossil fuel resources in order to control environmental damage. To apply this, the share of each sector in energy consumption should be determined. Figure 1-2 represents energy consumption by each sector in Canada. Interestingly, residential buildings stand in second place after the industrial sector. However, the industrial sector is not limited solely to the energy of manufacturing products. Part of this energy is for running heating, cooling and lighting in industrial buildings. With the same logic, part of the energy used in the industrial sector goes to the running of commercial buildings. Therefore, the share of buildings as a total of industrial, commercial and residential is higher than the 16% energy consumption in the whole picture. Thus, buildings have a significant share in using energy.

For this reason, this thesis focuses on using energy in buildings. Based on availability of information for residential buildings, studies are conducted on the residential sector. However, the principles are the same and can be applied to any industrial and commercial building.

Figure 1-3 illustrates energy consumption in the residential sector. In each process, the consumption of energy inside the house is determined. Based on Diagram 1-3, space heating has the biggest share of energy consumption - 59% of all energy usage is for heating the environment. –During Canadian winters there is a great need for energy to warm up homes and buildings. In second place is energy consumption for heating water in residential buildings, followed by appliances and lighting. By considering the share of energy consumption, the priority of study in each sectors shows up.

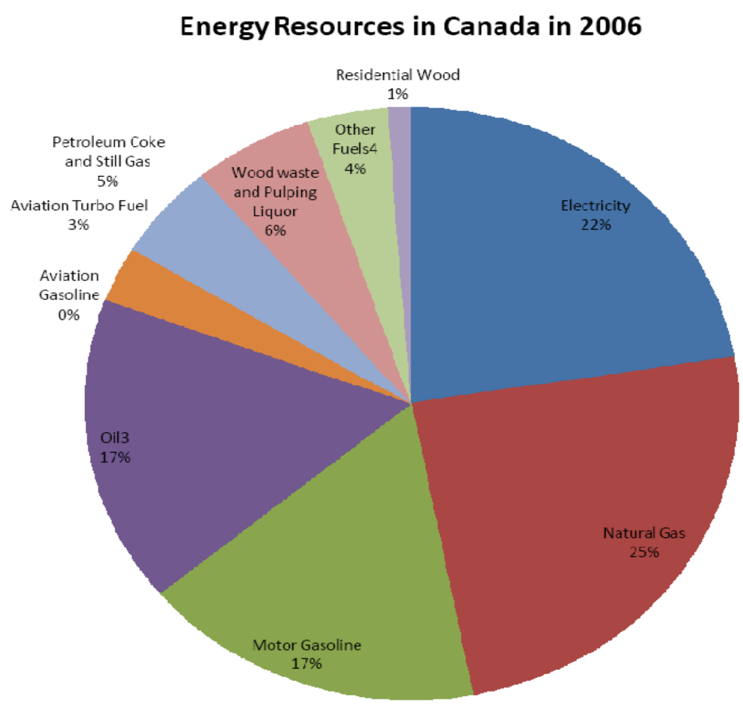


Figure 1-1, Energy Resources in Canada, Source: Natural Resources Canada (2009)

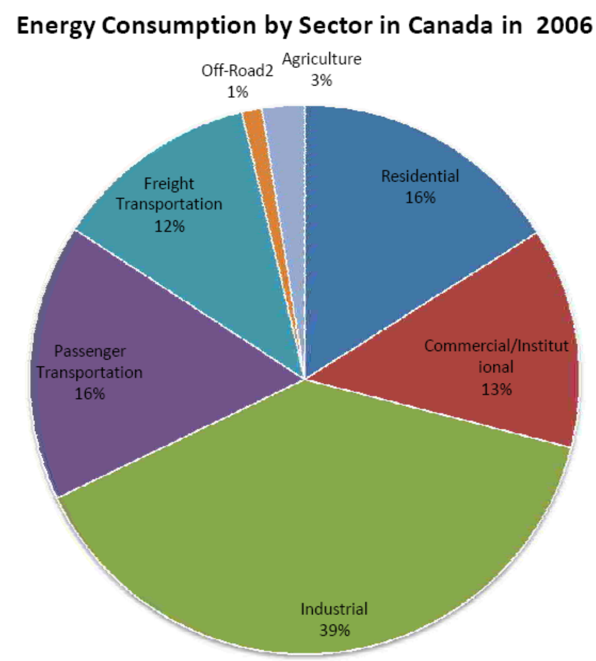


Figure 1-2, Energy consumption by sector in Canada, Source: Natural resources Canada (2009)

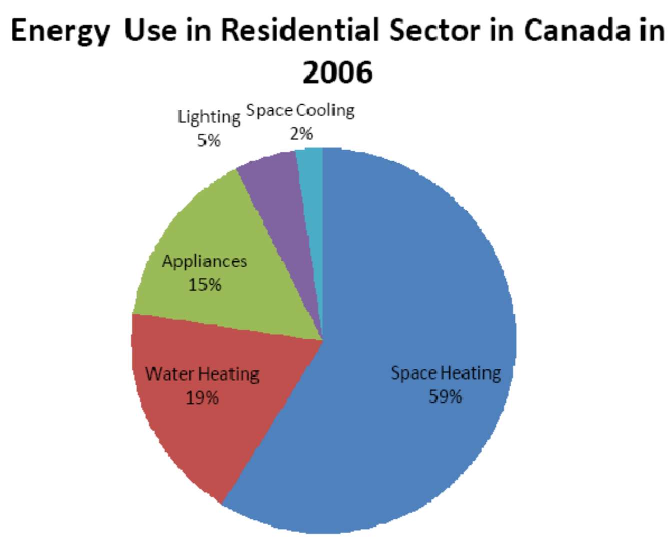


Figure 1-3, Energy consumption in the residential sector, Source: Natural Resources Canada (2009)

1.6. Emissions in Canada

As briefly mentioned in section 1.5, by generating energy, harmful emissions are produced automatically. The real concern here is the emissions that result from producing energy. The main purpose of all activities is to control harmful emissions. Below are diagrams illustrating the sectors which produce the highest emissions?

Figure 1-4 depicts the GHG emissions generated by each sector in Canada. Based on this diagram, transportation comes first, industry places second, and residential is in third place. These are the main areas to tackle in reducing GHG emissions.

In the last section, the residential sector is the highest priority sector for studying based on energy consumption. Figure 1-5 shows the GHG emissions in the residential sector. According to Figure 1-5, space heating creates 57% of GHG emissions in the residential sector, water heating and appliances stand in second and third places - exactly the same results as energy consumption in residential sectors. Threfore, the main focus of study should be on space heating, water heating and appliances.

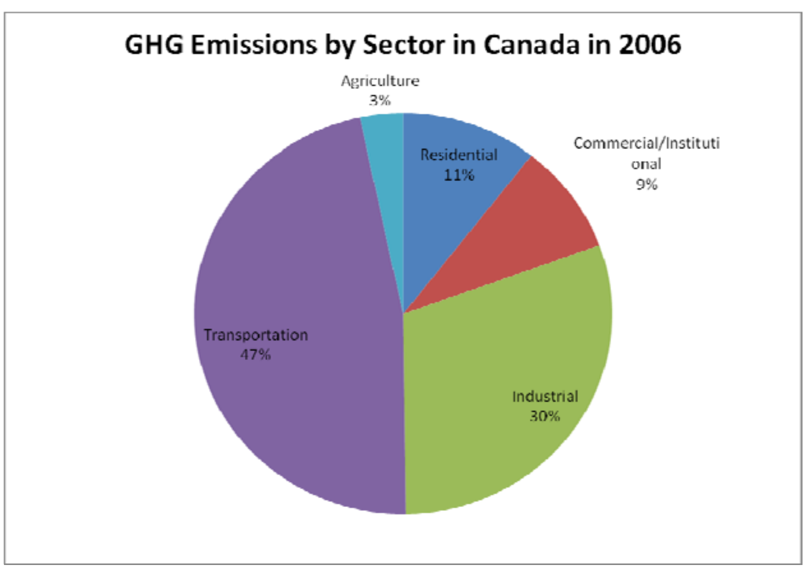


Figure 1-4, GHG emissions by sector in Canada, Source: Natural resources Canada(2009)

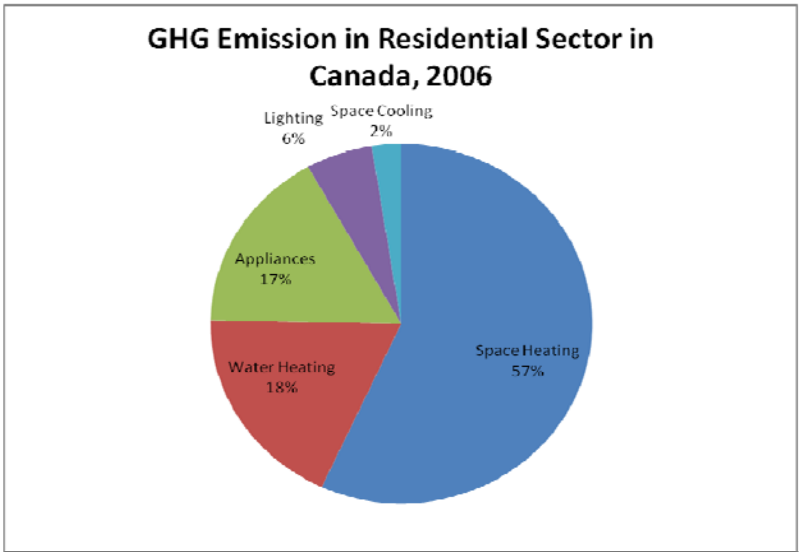


Figure 1-5, GHG emissions in residential sector in Canada, Source: Natural Resources Canada (2009)

1.7. Summary

In this chapter, the ways that humans can live on earth using sustainable, renewal and responsible energy are explained. The curve of man's attitude towards energy and natural resources, since the last century, is touched upon. The role of the over-using habit in producing greenhouse gas emissions (GHG) is demonstrated as well. One of the major environmental issues, climate change, is described. Emissions from cooling and heating buildings are the most important factor in climate change. Climate change, as a dangerous phenomenon, must be controlled in the new century; otherwise humankind should expect destruction of water, air, forest and many species of animals and plants as a result of global warming. Scientists' plans for energy conservation in the UK, Australia, Greece, Switzerland, China and Canada are suggested and quoted in this chapter. Stratospheric ozone depletion as another major effect of environmental problems is defined. Emissions from combustion engines using fossil fuel, CFCs, (which are used in refrigeration and air conditioning equipment) are the most important contributors in ozone layer depletion. This reduction of the ozone layer plays a major role in increasing skin cancer and eye damage. And last, but not least, acid rain is described. Electric power generation, heating buildings, and industrial consumption are identified as the key factors for acid rain. All research papers suggest using low carbon fuels and/or renewable energy to run equipment and reducing energy consumption by smart use of energy. Renewable energy and limited use of fossil fuels as the best solutions for environmental issues are explained. Renewable energy systems are the most efficient and effective solutions, categorized in five groups. However, the sun is the real source of energy for other types of energy. Geothermal energy as hidden thermal energy is able to transform into physical work. Wind energy can produce electricity or perform mechanical jobs by wind turbines or wind mills. Solar energy can provide man with electricity by PV solar panels or by creating a heat source for heating space or water with solar water heaters. There are many other devices to transform solar energy into useful applications like solar cookers. Biomass releases energy from plant and animal wastes, and can be categorized as a low carbon fuel as well. Hydro energy is the energy hidden in water at different levels, and can run mechanical devices and produce electricity for man. While hydrogen energy is not a renewable energy, it is a clean energy which can replace conventional fuels. Advantages of solar and wind energy are counted as the most practical energies in all levels of society.

Finally, the energy crisis is narrowed down to Canada, and more information about Canadian energy consumption is provided. Then, the importance of energy consumption in buildings and the role in pollution is mentioned.

Chapter 2: Motivation & Objectives

2.1. Motivation

As mentioned in the previous chapter, energy problems creating serious environmental issues are the crucial problems of the century, and the solution lies in applying renewable energy technologies. At this point, the question is what kind of renewable energy is the best fit for any particular building? The answer to this question is the main motivation of this thesis, finding alternative energy for different kinds of buildings. These technologies are applied in detail to each case study in order to find out what the best option is. Since we are living in Canada, case studies are in Canada, Ontario, and the greater Toronto area. The results of this thesis are a good tool for comparing different methods of generating energy through natural resources. The comparison is from different aspects. The possible aspects any building owner/management can think of are considered in prioritizing the technologies.

2.2. Thesis Outline

Chapter 3 covers the main area of producing greenhouse gas emissions in the building sector; methods of energy rating of buildings are explained. Each method, created, based on specific priorities, is cited; pros and cons of different techniques of building rating are mentioned. Efficiency as the main concern in energy conservation is also defined. Energy as a tool to show areas of improvement in energy conservation is elaborated upon; and then efficiency and energy, efficiency and appliances, efficiency plans on a large scale as in China, and efficiency in power plants is explained. After that, practical tips for smart use energy for households are described. Next is public energy use, and how to implement technical discovery in a community. What are some hindrances in using renewable energy? What are the challenges in changing public attitude from conventional energy to clean energy? People techniques are mentioned to address all these issues.

In Chapter 4, the function of the grid in designing a renewable energy system is explained first, and then different types of grid tie versus off grid systems are described. Pros and cons of each system are clarified. In the second stage of design, the type of equipment which converts natural energy to useful energy must be chosen. Based on this fact, the most popular ones are solar water heaters, photovoltaic (PV panels), and wind turbines, all of which are explained from two different aspects - the structure and the performance of equipment.

In Chapter 5, details of the calculation for renewable energy are described. Calculations for PV panels' arrays in different methods and the most popular one for the grid time system are given in detail. The application of these equations is explained in Chapter 6 case studies. Then, the calculation for wind turbines is clarified. However, because of the nature of the case studies, wind turbine equations are not used in this thesis. Afterwards, the financial calculations are elaborated upon in two equations, first in the "future value" equation which shows the values of money in the future, and in the second equation, "mortgage formula", which is a tool used to calculate the monthly payment of a loan. These financial equations are used in Chapter 6 for each case study in the cost analysis section.

In Chapter 6, diverse buildings are considered as case studies for using renewable energy. Various options are measured for the energy technology, emission reduction and cost analysis, however in the energy section different options of renewable energy technology are assessed. There are some incentives from the government allocated to renewable energy projects. Case studies in the financial analysis section are calculated based on receiving or not receiving governmental rebates. These case studies are residential buildings, industrial buildings and a public library. Case study #1 and case study #2 are two detached houses with different energy consumption regimes which are categorized as the residential buildings. Case #3 is a large public library characterized as the commercial building, and in case #4, the plastic injection company is branded as the industrial.

In Chapter 7, data resulting from the previous chapter is analysed based on technological view, environmental aspects, and budget. Meanwhile, from the point of energy conservation, some recommendations for each case are suggested because ultimately, saving energy is much cheaper than generating energy.

In the last chapter, Chapter 8, there is further discussion on better choices of alternative energy by considering other parameters rather than cost, environment and technology. Finally, the future study is introduced.

Chapter 3: Literature Review

3.1. Introduction

This chapter covers the main area of producing greenhouse gas emissions in the building sector; methods of energy rating of buildings like LEED, BEREEAM, HK-BEAM are explained. Each method is created based on specific priorities, followed by pros and cons of different techniques of building rating. Efficiency as the main concern in energy conservation is defined. Energy as a tool to show areas of improvement in energy conservation is elaborated upon; and then efficiency and energy, efficiency and appliances, an efficiency plan on a large scale as in China, and efficiency in a power plant is explained. After that, practical tips for smart use energy for households are described.

Next is public - how to implement technical discovery in a community. What are some hindrances in using renewable energy? What are the challenges in changing public attitude from conventional energy to clean energy? According to studies, some people techniques are mentioned to address all these questions.

3.2. Building Sector

According to Pitts and Smith (1997), 4.5 out of 6 billion tonnes of carbon emitted by human activities belong to industrialized countries, half of which is over the buildings. For example, in Europe, 40% - 45% of consumed energy is expanded in the building sector, with approximately 67% of this amount being used in private buildings (Zografakis 2000). Meanwhile, Hodder et al. (2002), Heidari and Sharples (2002), and Yannas (1994), report that in industrialized countries, 50% of carbon dioxide emissions come from the building sector. Solar energy is 13 % of energy consumption in buildings, and it is supposed to be 50% by 2010, possibly 57% in some areas (Kavalari, 2001). That is the reason why studying buildings and working on finding methods of increasing a building's efficiency is so important. Paravanits and Markis (2007) explain that energy efficient buildings may lower carbon emission by 60% or more, which is equal to 1.35 billion tonnes of carbon, the amount of savings proposed by the Environment Conference in Rio and Berlin. Energy efficient buildings also use conventional energy sources and rely on oil. Over and above the major savings in energy usage and cutting down in greenhouse gas emissions, measuring building energy consumption has drawn much attention recently. Government Newspaper (1998), Akbari and Sezgen (1992), Argiriou et al. (1994) and Balaras et al. (2003) attribute a significant factor in modern architecture (Donald, 1998). By rating the buildings, possible areas for improving the structure can be determined. The different methods for rating buildings are explained in the following paragraphs:

3.3. Building Rating Schemes

House Rating Schemes (HRS) act like a tool to evaluate a residential building's energy performances. Different definitions for HRS have been developed so far. Each definition is created based on research or a new demand of energy definition. Santamouris (1995) classifies these different methods as follow:

- The most popular method is normalising energy consumption by considering building size and annual energy consumption, divided by heated floor area, SIA (1983), or by volume (Regles, 1988).

- Fels (1986) introduced the Princeton scorekeeping method (PRISM), applied energy signature, between heating energy consumption and outdoor temperature (Favre et al. 1981, 1983).

- Zmeureanu et al. (1992, 1998) developed the normalization method to investigate utility bills for heating and cooling in buildings.

- The Energy efficiency office in the UK built up the normalized performance indicator (NPI) for building offices by considering building size, operating hours, internal temperature and wind contact.

- The building energy and environmental assessment method (BE2AM) was added to the THRMIE program. The goal of this package was to analyze the design stage, the energy and environmental effects of buildings in Europe. The BE2AM content is life cycle assessment through applied energy, appraisal of material if they are environmentally friendly, and assessment of environmental design.

- Gareston (1990) developed the building research establishment environmental assessment method (BREEAM) which contained methods to analyse the environmental quality of different buildings. Methodology was combining inspections and questionnaire and some environmental factors. BREEAM could not address energy use directly.

- Dhalsven and Pagerhaung (1994) present the “Key number”. These numbers of energy performances differ in buildings and countries.

All of these methods cannot be used for multi-criteria rating a building. BE2AM, PRISM and NPI are very energy conscious, BREAM is very country limited.

Dascalaki et al. (2002) define a method of multi-criteria to rate and rank the office buildings. It is called the Office Rating Methodology (ORME). The parameters they considered for their package include the following aspects:

1. energy consumption for heating, cooling and other appliances;
2. environmental impact;
3. indoor air quality (IAQ); and
4. cost.

This is one step further than Dascalaki’s and Santamouris’ (2002) remarkable research in considering cost as one of the parameters. Dascalaki and Santamouris conduct a large project to establish global retrofitting strategies, methods and design guidelines to sponsor winning cost-effective applications of passive solar plus energy efficient retrofitting measures to office buildings. Ten office buildings in different European climates are chosen as case studies. These buildings are audited and monitored extensively. The results are classified in a handbook and an atlas.

Calla et al. conduct a research in Canada (1999). Based on their research, they suggest a system for rating buildings. It combines utility bills and computer simulations. 45 houses in Montreal are picked as samples to apply their rating method on. The major aims are:

1. to calculate the quality of the outcomes by the suggested system (like thermal resistance of the exterior, air infiltration rate, energy performance of houses); and

2. to calculate techniques of measurement and simulations (like accuracy of measurement and simulation, on site time demand for collecting data on site).

In conclusion, the rating system uses the energy history of the house as the initial source of data to analyse the energy performance index they suggest.

Santamouris (1995), DePani et al. (1999), Bloem et al. (2001), Dascalaki and Santamouris (2002), Bolan et al. (2003), Doukas et al. (2005), Granada et al. (2006), and Chen et al. (2006), state HRS is somewhat of an “energy indicator” to evaluate energy performance in buildings, which is normalized by space of dwelling. The reasons behind these facts are:

1. Energy symbolizes a high percentage of the operation cost of a building. It plays a key role on thermal and comfort of the tenants.

2. There is a difference between real energy consumption and calculated energy loads. HRS is much closer to the real number, though it gives an idea for the final energy cost.

3. HRS is a good tool to determine and choose the suitable HVAC equipment for buildings, both heating and cooling.

Ballinger (1988) explains the use of fossil energy for heating and cooling buildings, however, sustainable energy helps to moderate climate changes. It can happen by minimizing or avoiding artificial heating and cooling. This energy customization depends on climate, in other words, design optimization is different in Canada and Australia and Europe, as HRS are different.

3.4. Building Environmental Assessment

Following the building rating and methods, the most practical and most recognized building environment assessment schemes are explained and compared.

3.4.1. Leadership in Energy and Environmental Design (LEED)

USGBC (2007) explains LEED was established by the US Green building Council (USGBC) for the US Department of Energy. Lee and Burnett (2008) report the first version of LEED launched at the USGBC membership summit in 1998. Some modification was applied to Version 1.0 in Version 2.0 which was released in 2000. Since then, different versions of LEED have been released based on market demand and modifications. LEED for new construction building was released in 2005, and LEED for building types, including schools, homes, offices, etc. was released in 2006. LEED is the most popular building assessment scheme. It is actively in use in 24 countries, with Canada being one of the pioneers in using LEED.

Essentially, CAGBC (2009) state that LEED promotes a whole-building approach to sustainability by detecting performance in five categories of human and environmental health:

- sustainable site development;
- water efficiency;
- energy efficiency;
- materials selection; and
- indoor air quality.

Each category has its own sub-categories and related points. LEED is based on points in each inspected building. According to Wikipedia, points have been distributed (Table 3-1.)

Required "prerequisites" in each category receives no points.

Table 3-1, LEED point system requirements

LEED Requirements	Detail
Sustainable Sites *Needed points* ***14 points***	• Construction Activity Pollution Prevention Plan (required) • Site selection (1 pt) • Development density and community connectivity (1 pt) • Brownfield redevelopment (1 pt) • Alternative transportation availability (3 pts) • Public transportation access (1 pt) • Bicycle storage and changing rooms (1 pt) • Parking capacity and carpooling (1 pt) • Reduced site disturbance (2 pt) • Protect or restore open space (1 pt) • Development footprint • Stormwater management (2 pts) • Rate and quantity (1 pt) • Treatment (1 pt) • Reduce heat islands (2 pts) • Roof (1 pt) • Non-roof (1 pt) • Light pollution reduction (1 pt)
Water efficiency *Needed points* ***5 points***	• Water efficient landscaping (2 pt) • Reduce by 50% (1 pt) • No potable use or no irrigation (1 pt) • Innovative wastewater technologies (1 pt) • Water use reduction (2 pt)
Energy and atmosphere *Needed points* ***17 points***	• Fundamental commissioning (required) • Minimum (code) energy performance (required) • Fundamental Refrigerant Management (required) • Optimize energy performance by 14% (new) or 7% (existing) buildings (2 pts, required as of June 26, 2007) • Energy optimization (8 pts + the 2 required above) • On-site renewable energy (3 pts) • Ozone depletion (1 pt) • Measurement and verification (1 pt) • Green power (1 pt)
Materials and resources	• Storage and collection of recyclables (required)

LEED Requirements	Detail
Needed points ***13 points***	• Building reuse (3 pts): • 75% reuse of building structure and shell excluding windows (1 pt) • 100% reuse of building structure and 50% of walls, floors, ceilings (1 pt) • Construction waste reuse or recycling (by weight or volume) (2 pts): • 50% diversion (1 pt) • 75% diversion (1 pt) • Reuse of existing materials (by cost) (2 pts) • 5% salvaged or refurbished materials (1 pt) • 10% salvaged or refurbished materials (1 pt) • Recycled content (2 pts) • Criteria vary in recent versions of LEED, but depend on value of pre- and post-consumer recycled content (2 pt) • Use of local materials (2 pts) • Fabrication shop within 500 miles (800 km) of building site and raw materials source within 500 miles (800 km) of building site, 10% (1 pt) or 20% (+1 pt) • Rapidly renewable materials (1 pt) • Certified Wood (1 pt)
Indoor air quality *Needed points* ***15 points***	• Minimum indoor air quality (required) • Environmental tobacco smoke control (required) • Outdoor air delivery monitoring (1 pt) • Increased ventilation (1 pt) • Construction indoor air quality management (2 pt) • Indoor chemical and pollutant source control (1 pt) • Controllability of systems (2 pt) • Thermal comfort (2 pt) • Daylight and views (2 pt)
Innovation and design process *Needed points* ***15 points***	• Points for this category are awarded above and Beyond the score 64 points, and are described as rewarding strategies that go above and beyond the criteria for those points.

According to Eberly, D. (2008) business benefits of LEED are:

- lower costs for energy and water;

- lower costs in waste disposal;
- lower costs for emissions/environmental;
- lower costs on operation and maintenance;
- increased productivity of building occupants;
- positive influences on the local environment; and
- set goals for facility management's building to incorporate in future campus building development.

3.4.2. Building Research Establishment Environmental Assessment Method (BREEAM)

The Building Research Establishment (BRE) launched the Building Research Establishment Environmental Assessment Method (BREEAM) in the UK in 1990 (Prior, 1993), (King, 1998). BREEAM version 1 for the office was released in 1993; and version 2 launched in 1998 (Lee and Burnett, 2008). A non-domestic version of BREEAM released in 2004 covers offices, industrial premises, retail outlets, schools, etc. (BREEAM (2004). It is the best scheme and covers 15-20% of new office buildings in the UK (Larson, 2000). While other rating schemes were developing in Canada, New Zealand, Norway, Singapore and Hong Kong, BREEAM was considered as a reference model, BREEAM (1996).

In BREEAM (2009), site benefits of this scheme are as follows:

a. Benefits for occupiers

- improved internal environment;
- increased flexibility; and
- reduced operating costs.

b. Benefits for designers

- enhanced knowledge;
- improved image;
- more efficient project management;
- client satisfaction; and

- reduced capital costs.

c. Benefits for investors and developers

- enhanced marketability;
- increased flexibility; and
- good return on investment.

3.4.3. The Hong Kong Building Environmental Assessment Method (HK-BEAM)

The Hong Kong Building Environmental Assessment Method (HK-BEAM) launched in 1996 as a voluntary scheme, HK-BEAM (1996). HK-BEAM was released in 2 versions, one for new (HK-BEAM 1/96) and the other one for existing office buildings (HK-BEAM 2/96). It addresses a wide range of issues relating to the influence of buildings on the environment - globally, locally and indoors (Lee and Burnet, 2008). An additional version of HK-sor residential building was released in 1999, LEED (2001). HK-BEAM 96 was developed based on years of implementation and expanding the range of building types that the scheme could address in 2003 and 2004; the new versions for new buildings (4/04) and for existing building (5/04) launched in 2005 (HK-BEAM Society, 2004). Burnett and Lee (2008) report HK-BEAM has assessed more building space based on per capita.

According to the HK-BEAM website (2009), the benefits of HK-BEAM scheme certification are:

- cost savings through more efficient use of energy and resources;
- increased occupant satisfaction from healthy and productive accommodation;
- assurance that best practice management is achieved and liabilities reduced;
- enhanced corporate profile and marketability to potential building users; and
- a tool to improve purchaser choice and information.

3.4.4. Comparison of LEED, BREEAM and HK-BEAM

Table 3-2 shows comparisons between HKBEAM, LEED and BREEAM in different aspects. LEED follows the improvement of the energy system year by year while BREEAM sets the numbers. HK-BEAM is setting goals as well as seeking improvements annually.

Table 3-2, General Comparison (Burrnet and Lee, 2008)

Item	HKBEAM	LEED	BREAM
Assessment method	Mixture of performance based and feature specific criteria	Options of feature specific criteria and energy cost budget method	Mixture of performance based and feature specific criteria
Simulated tool	HTB2+BECON or approved equivalent	DOE-2 or BLAST or approved equivalent	No specific requirements. Actual consumption figures may be used where available.
Scope of assessment	Annual energy use, Maximum electricity demand, Energy efficient design, Envelop performance	Energy efficient design, Annual energy cost	Annual CO2 emission, Energy efficient design
Maximum credit level performance based criteria	Reduction of 57% in annual energy use over the baseline case	Reduction of 60% in annual energy cost over the budget	Zero emission
Minimum credit level performance based criteria	120 kWh/m2/yr	Reduction of 15% in annual energy cost over the budget	160 kg CO2/m2/yr
Baseline case/zero credit level	Compliance with the minimum requirement laid down by relevant laws or codes of practice	Compliance with ASHAE/IENSA 90.1-1999[38]	Compliance with DETR(1998) good practice guides
Energy related credit/ points (%)	23	25	20

Table 3-3 shows the difference between LEED and HKBEAM from the point of indoor design conditions.

Burnett and Lee (2007) ran the study to benchmark energy use assessment of LEED, BREEAM and HK-BEAM. The study was conducted on an earlier version of this energy assessment scheme. The study concludes that:

- the operation ranks of the baseline buildings are comparable.

Table 3-3, Baseline Energy Use (Burrnet and Lee, 2008)

Indoor design condition	**HKBEAM**	**LEED**	**Difference**
Ventilation rate (L/s/m2)	1.1	0.4	0.7
Indoor set-point temperature (°C)	25.5	23.9	1.6
Lighting power density (W/m^2)	25	14	11
Equipment power density (W/m^2)	25	8	17
Infiltration rate (L/s/m^2)	0.09	0	0.09
Assumed COP	2.7	2.7	0
Overall baseline energy use increase	+ 38 kWh/m^2		

- the imitation tools are fulfilment of the ASHRAE Standard 140;
- The market positions of the approved buildings are in the top 25%;
- the differences in energy use measurement methods, baseline buildings, simulation tools and operation criteria do not touch the assessment results;
- it is not easy to score credits under BREEAM; and
- buildings that score outstanding energy performance under HK-BEAM, BREEAM, and LEED belong to the top 5% in the market".

3.5. Efficiency

King and Kordjamshidi (2009) conduct an experiment in Australia to show an efficient design for houses. First they run the house in the free-running operation mode, and then they run the same house in an efficient design condition operation mode. The energy consumption is totally different and based on that they state the present energy base rating scheme is not able to assess the performance of passive design in a moderate climate. They use simulation to calculate the thermal performance of houses and appliances multi-regression analysis to develop the new framework. The new framework suggests reducing energy needs for heating and cooling in comparison with the present energy based rating scheme in the Australian environment. Studies strongly recommend developing a new rigid framework for moderate climates.

Markis and Paravantis (2007) run an exceptional study on energy consumption in small enterprise in Greece. They believe industrial buildings have higher thermal loads, longer operation hours, and higher air change in comparison with other non-residential buildings. Markis and Paravantis assess energy conservation measures in major waste areas for small business buildings as follows:

1. building envelope;
2. artificial light;
3. heating, cooling and refrigeration systems;
4. water and space heating;
5. electrical and mechanical equipment; and
6. distribution and transportation.

Based on this study, air conditioning followed by electromechanical equipment, water and space heating, artificial lightening and building envelope are the priorities in wasted energy control. However, reducing waste in electromechanical equipment is addressed better by companies in comparison with other issues. In spite of the high cost of cutting down waste, in some cases, energy conservation is somehow covering that cost.

3.5.1. Efficiency and Appliances

While many scientists focus on building efficiency, some associates conduct studies about efficient appliances and their role on reducing energy consumption. Ugursal and Fung (1988) point out in their research that through improving efficiency in residential building in Canada, the total end use energy shrinks and obviously carbon dioxide emissions shrink, however, this reduction is tiny and the bigger goal should be to reduce heating and cooling energy to drop greenhouse gas emissions effectively.

Young conducts other research (2008) on energy efficient appliances to show the potential of reduction in energy consumption in residential areas; however, this reduction will be done slowly in time, by replacing older models with new, more efficient appliances. Also, Young finds the Canadian pattern for changing appliances is different from the available models. However, the rate of appliance retirement depends on household characteristics like income and environmental awareness. Young quotes the rate of replacing appliances has a strong relationship with the realization of household energy demand and savings in response to technological upgrading by household. Part of this energy efficiency improvement is due to the standard enhancement, and the other part is due to the technology development (Kim et al., 2005), (Koomey et al., 1999), and (OEE, 2005).

3.5.2. Efficiency in Large Scale

While Canada,, with 33 million in population working on different efficiency projects, China with 1.3 billion people has started to work on efficiency on a large scale. China is in a position of high energy intensity over the enormous economic growth after 2000; fast economic growth causes a shortage of energy and other resources in which the Chinese do get a chance to phase out old and inefficient equipment; moreover, fast economy attracts people from the agricultural sector to the industrial sector which is more in energy demand. The industrial sector is running with old and inefficient equipment, though energy consumption in China is high and inefficient (Yang, 2008). Yang also explains about China's government target for reducing energy intensity by 20% in 2010 compared to 2005, through upgrading production technology and restructuring of the economic system. The Chinese government planned energy intensity shrink will implement 45% to the total energy efficiency enhancement, and the rest of the 55% will be achievable through:

1. rearranging the country's economy from energy-intensive to non-energy-intensive;
2. applying more high-quality energy;
3. developing technology;
4. applying better raw material for manufacturing; and
5. developing energy system management (Yang, 2008).

3.5.3. Efficient Power Plants

The district energy system of housing, practical in congested populated urban areas like downtown Toronto, is a technology with the concept of centralized heating equipment, distributing the hot/cool air to several buildings. In this system, heat loss is minimized with special designs based on Combined Heat and Power (CHP) concepts. According to the Wikipedia definition, Combined Heat and Power (CHP) is an all encompassing system generating both heat and power by a heat engine and a power station. This method is functional when electricity and heat are in demand. In all power plants, generating electricity produces heat as a by-product. Usually this heat gets captured by a cooling tower. In CHP plants, this heat by-product is produced for an industrial or domestic heating job. In Europe and particularly in Scandinavia, this heat is absorbed for heating the water. There are 7 CHP plants in the US to feed 100,000 buildings in Manhattan. CHP is a thermodynamically proficient use of fuel; this heat is not waste.

Hennells (2008) cites that CHP has giant potential to deliver energy savings and apparently harmful emission drop and cost savings; CHP is future technology which could guide more efficient CHP power generation to apply lower carbon fuel, renewable energy technology; the key factor is the generation of the right market framework to deliver CHP. Also, Hennells categories improving the CHP through:

- modification of the efficiency of electricity generators;
- application of lower-carbon and renewable fuels; and

- modification of new products for new end uses (including the micro-CHP and CHP in heat networks).

3.6. Perception of Renewable Energy

In studying the application of renewable energies, the environment and technology are considered quite seriously. Numerous studies are conducted to investigate these two factors. Unfortunately, in most of the research, the “human” is excluded from the studies. Humans are not only part of the environment, but also the main factor as users of the technology. Humankind is the centre of the earth in the real world. Occasionally, some research is conducted to investigate the role of people in using renewable energy and methods of drawing clean energy to the attention of the public.

Calla et al. (1999) conducts research in Canada. They suggest that by the actual energy performance and comparing modified houses, owners could be educated about methods of potential savings, which could be imitated by renovating the houses and changing the public habit toward energy consumption.

Mitchell et al. (2006) cites development toward adding renewable energy capacity in the UK has been slowed down. It is not certain the UK will reach the target of using 10% renewable energy by 2010.

Rogers et al. (2008) mentions this delay is calculated due to technical, economical and social factors, however, public opposition to wind energy and bio energy is a serious matter. Sinclair and Lofstedt (2001), Toke (2005), Upham and Shckley (2006), Upreti (2004) believe the most important factors for public opposition are inappropriate scale of development, a disappointingly high ratio of local cost to local benefits, and an insufficient communication with neighbourhoods by the developer.

Devin-Wright (2005), Gross (2007), Upham (2006) and Shackley (2007) show public behaviour toward renewable energy could be positive when people would welcome more participation in clean energy development. Giddings (2007), Underwood (2007), and Kellet

(2007) state there should be a higher degree of public involvement in local energy development. This can be done by the expansion of a decentralized community-based renewable energy plan, especially in rural areas. Letcher et al. (2007) cites that community initiatives to deal with climate change need access to a “trusted resource base” with knowledge in both community development and technical issues.

Rogers et al. (2008) conducts research regarding public perceptions on community based renewable energy projects. In one particular case study (Thirlmere in UK), where the methodology was a questionnaire survey and semi-structured interviews were conducted, in nut shell, the findings link the advantages of providing support for the growth of community-based energy projects and regional renewable energy provisions. There is likely to be enthusiasm for such initiatives and aspiration for involvement. However, the structural barriers show that more institutional support from regional authorities is required to facilitate both projects and participation. Crystal frameworks with public awareness are likely in demand for a wider span of communities to undertake projects.

Schweizer-Ries et al. run similar research to investigate public acceptance of renewable energy projects in Germany in 2008. The results point out that economic consideration of the renewable energy system, considered a positive cost benefit calculated by the public, is the robust factor for a reported acceptance. Moreover, the role of landscape evaluation is very important, plus accurate information and sufficient communication during planning and installation are very crucial to public acceptance. Besides, operating company commitment on district levels as well as general public involvement and location of the project in the community are important factors for acceptance in the implementation stage.

Steg (2008) conducts a study to point out the methods to promote energy conservation to the public. In general, households should change their attitude toward energy conservation to slow down the issues caused by increasing levels of fossil energy consumption. The hindrances to use non-fossil fuel energy are: inadequate knowledge of effective methods to reduce household energy use; lack of concern for saving on the high cost of energy; and lack of practicable alternatives. The effective strategy to target mentioned barriers is educating the general public on energy saving. It is achievable through changing public awareness, motivation and norms.

While many studies cite public attitude will be changed by awareness, communication and participation, Al-Ghandoor et al. (2008) explains that an increase in electricity and fuel price would not change public energy consumption.

Markis and Paravantis (2007) point out in their study regarding energy conservation in small enterprises that important reasons for failing to adopt energy conservation measures are:

1. lack of information;
2. organization structure; and
3. technical and financial problems.

Akbari and Sezgen (1992) come up with similar results for the companies: lack of information and financial problems are barriers for business owners to adapt energy conservation practices.

Berg and Hassett (1984) show the same results - information and institution are the major hindrances for upgrading energy systems.

3.7. Summary

In this chapter, buildings' contribution in producing greenhouse gas emissions is presented through different studies in different countries; almost all researchers agree that 50% of the share of greenhouse gas emissions is attributed to the building sector. This percentage shows the importance of focusing on building energy conservation. One step in studying buildings energy consumption is rating the building from the point of energy, then work on improving the rate. Different scientists, based on different priorities, come up with a method to measure building energy performance; these methods are presented with pros and cons. The brilliant result putting together all comparisons is to customize energy design for buildings based on environmental circumstances and available resources. Therefore, there is not a general solution which can apply to all buildings in every country. Efficiency is the definition which is explained as an introduction to review studies on efficiency and methods using effective energy in home buildings and business buildings, the sectors receiving the most attraction in each sub-sector. Appliances' energy consumption is the field covered, however, it is a small portion of energy; appliances will be replaced with new low energy appliances based on household knowledge and income.

Efficiency by using energy in a smart way is designed in power plants as well; a CHP power plant is cited as a solution to better efficiency in energy production and consumption. The practical tips to reduce energy use for households are mentioned as part of smart use of energy. These tips are realistic in the kitchen, laundry, heating and cooling, lighting, heating water and running home energy efficiently.

The last part of Chapter 3 is dedicated to the public attitude toward renewable energy. People are the main factor in using renewable energy and the most important part of the environment; they are also most often not considered in many studies. Based on studies, communication in community clean energy projects, educating people, providing the practical technology, creating motivation in the community, defining the economic benefit of using renewable energy, and positively changing the public habit toward using renewable energy are most important. An interesting point is that fossil fuel cost has no effect on changing community attitude toward new energy systems.

Chapter 4: Renewable Energy Systems

4.1. Introduction

In this chapter, first the function of a grid in designing a renewable energy system is explained, and then different types of grid tie versus off grid systems are described. Pros and cons of each system are clarified.

In the second stage of design, the type of equipment which converts natural energy to useful energy is chosen. Based on this fact, the most popular ones are solar water heater's photovoltaic (PV panels), and wind turbines, and are explained from two aspects - the structure and the performance of equipment.

4.2. Grid Dependency or Independency

The first decision for designing a renewable energy system is clarifying the role of the electrical grid in design. Designer has 2 options, either design an independent power generation system without considering any role for the electrical grid, or consider some function for utility power in her/his plan. Therefore, two definitions are described, grid-tie or off grid.

4.2.1. Off Grid

Off grid is the option a designer must use when designing an independent power plant. In this design, no task defines for utility power. The reasons are:

- no grid is available in application zone (remote area); and
- grid independency is a design requirement.

An off grid design has the main basic components:

1. any renewable equipment as a source of energy (mostly PV panels or wind turbines);

2. bank of batteries to restore energy for the time natural energy is not available (night time, cloudy days, calm days);

3. charge controller to keep the batteries charged, but not too over charged; over charged batteries have a shorter life; and

4. inverter to convert DC current to AC current which is suitable for regular applications.

The designer should consider an off grid system where batteries hold the main portion of equipment costs; however, it works as a backup for the system or peace of mind. The higher numbers of the days without natural energy, the bigger the numbers of batteries, or the higher the costs for the design. Sometimes diesel generators are considered as a backup system. Diesel generators can be partial backup, the only backup, or even the replacement backup for the system. Design requirements and budget of the renewable energy project determines the details of the backup system for the designer.

PV panels work as the equipment, which convert sunlight to electrical energy, and wind turbines convert the wind's kinetic energy into electricity. Whichever system is used, both are able to apply the same power generation system. PV panels and wind turbines work as complementary systems in a way where they cover each other, when there is insufficient sunshine, wind turbines get energy from wind, and vice versa - when the weather is calm, the sun provides most of the energy. The backup system comes into the picture for limited times on cloudy calm days.

In Figure 4-1, a basic design of an off grid system is depicted. A table saw is an example for electrical application.

4.2.2. Grid Tie

In the grid tie system, utility power plays a role in the function of whole renewable energy power generation. The role of the electricity grid is defined in different levels, depending on the plan requirements. There are three main categories of grid tie systems.

Each group has its own pros and cons; conditions state which grid tie is the best fit for the project.

4.2.2.1 Grid Tie Without Batteries

In this system, there are two sources of electricity - one is the conventional electricity grid and the other one is a type of renewable energy source.

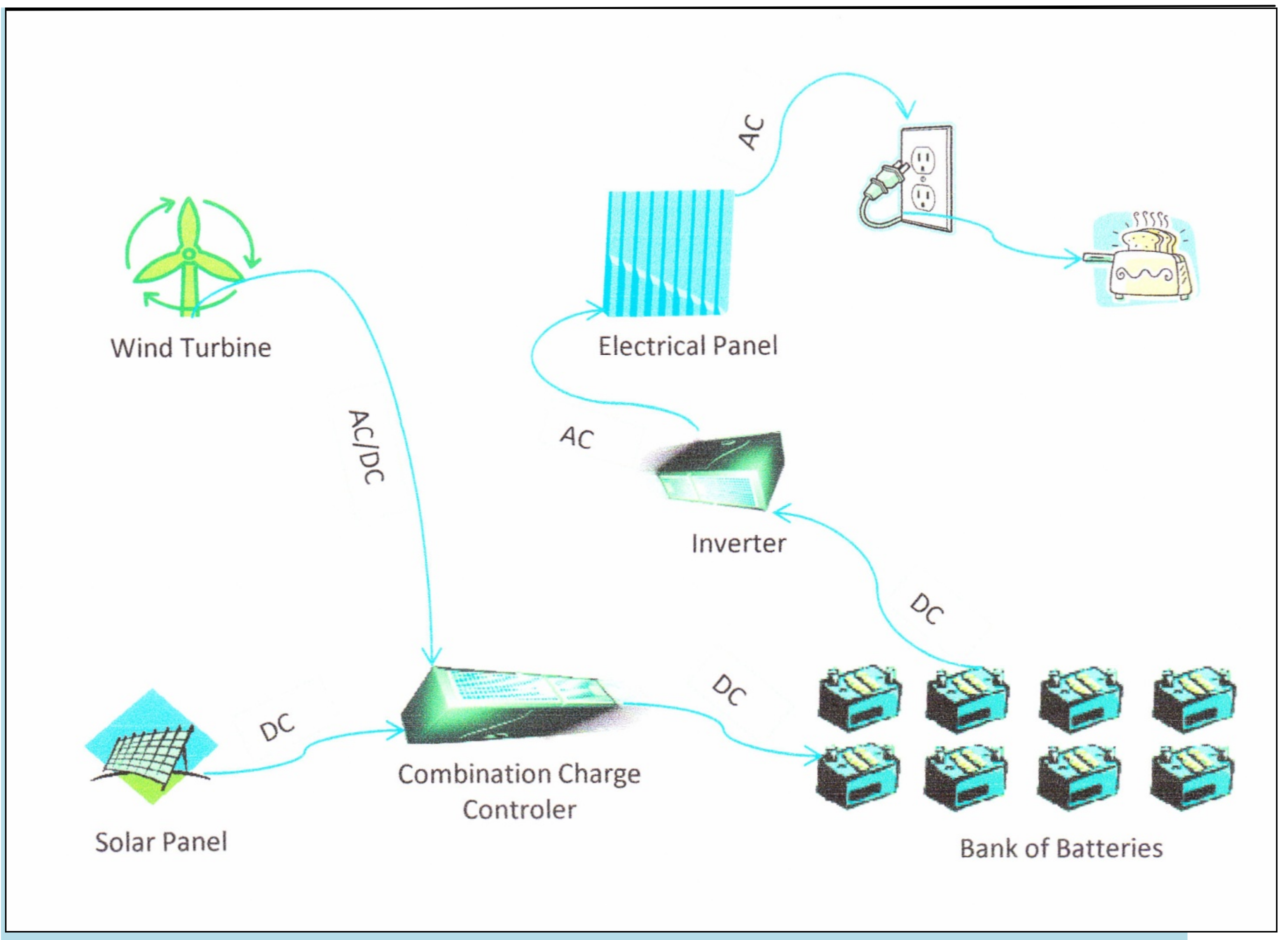


Figure 4-1, Off Grid system basic design (Modified from Ewing, 2003)

Electricity from PV panels or wind turbines passes through the “grid tie inverter” in order to convert to AC current, then suitable for utilities use. Both sources of electricity are able to provide electricity for utility; however the priority is with the renewable source of energy. In this type of grid tie system, the renewable source of energy produces electricity for all applications. If Mother Nature provides more energy, this electricity goes through the grid. It means the utility grid turns in the opposite direction. Usually hydro companies buy this surplus electricity. In Ontario, the cost to pay out to the consumer for this surplus electricity is higher than what the electricity is sold for; however, there is a cap for selling the electricity to the provincial government. Hydro One sells electricity for 10 cents per kW, and buys electricity for 15 cents per kW. Selling electricity is another advantage of this kind of grid tie system. In this system, return of investment (ROI) is faster.

There is no battery in the grid tie system design; the cost of running this project is much lower than the system which has batteries. However, when the grid is down, the whole system is down. In other words, on a sunny day in summer, if grid goes down, PV panels cannot feed the utilities, and on a windy day, if the grid is down, wind turbines are not able to run the internal grid. This is the main drawback of the grid tie system without batteries. Figure 4-2 shows a simple schematic of a grid tie system without batteries design.

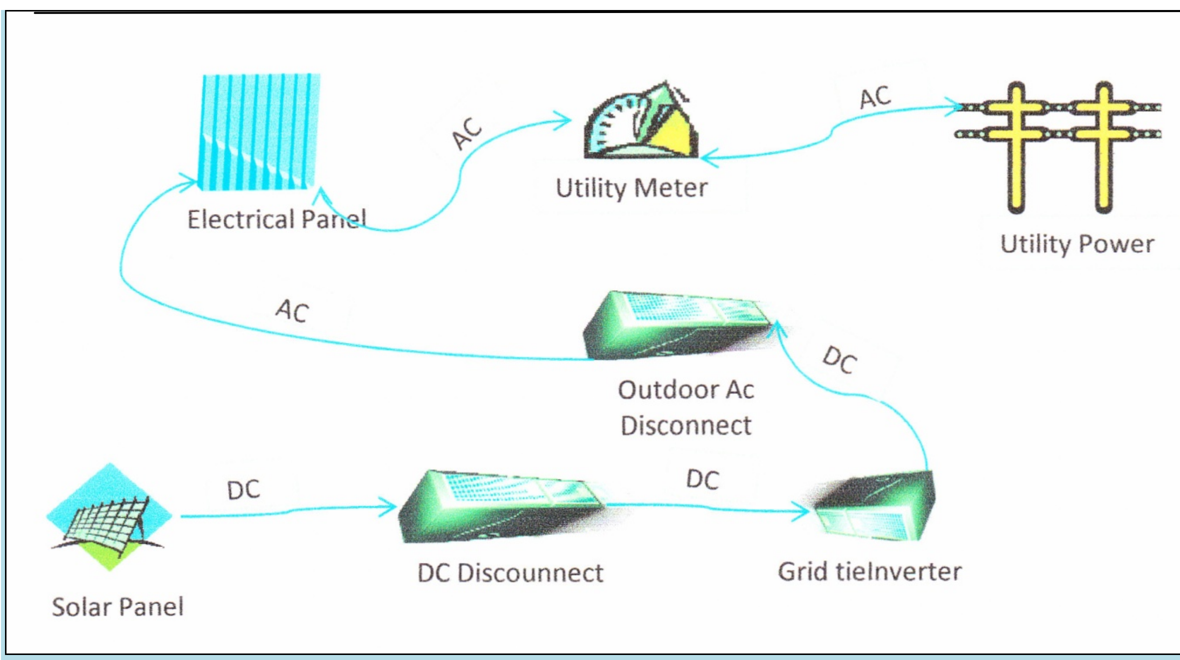


Figure 4-2, Grid tie without batteries (Modified from Ewing, 2003)

4.2.2.2. Grid Tie With Batteries

In this type of grid tie system, a critical circuit is defined and includes the necessary electricity applications for a building. The concept behind this design is to run the necessary devices/appliances when the grid is down. For this purpose, a set of batteries is designed based on critical circuits. As there are batteries in the system, the cost is higher than the grid tie system without batteries; however, the main problem with the grid tie system without batteries is resolved. Still, electricity can be sold to governments in this design, and the return of investment is faster in this type of grid tie system. Figure 4-3 is a schematic design of a grid tie system with batteries.

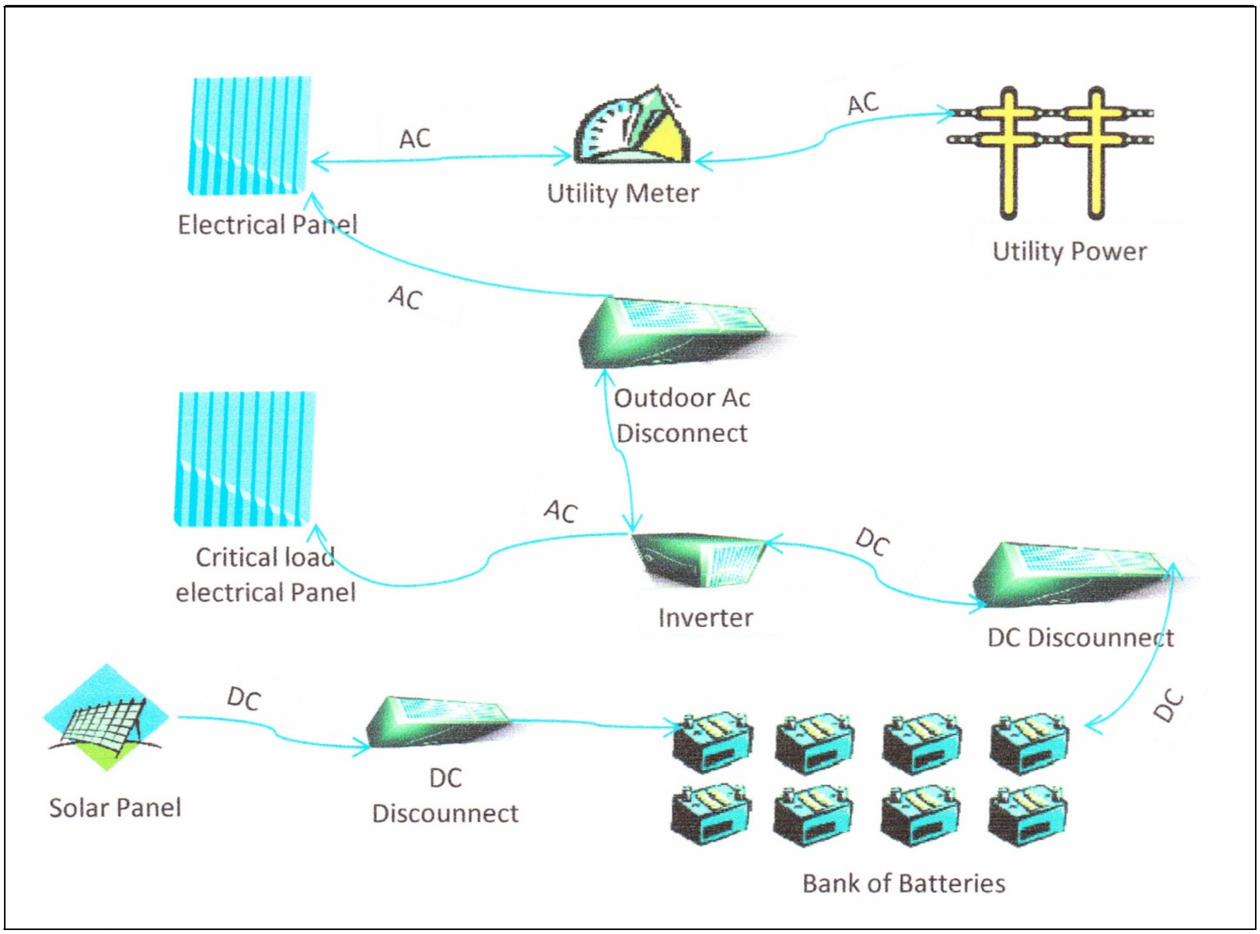


Figure 4-3, Grid tie with batteries (Modified from Ewing, 2003)

4.2.2.3. Grid Tie Parallel With Batteries

The grid has the least role in this type of grid tie system. The whole design system is very similar to the off grid system with a whole set of batteries as a backup system. The function of a grid in this type of grid tie system is to charge and keep the batteries. The most important advantage of this system is that when the grid is down, all devices/appliances run without any problem. However, in this type of grid tie system, surplus electricity is not able to go through the grid. In other words, the consumer/owner cannot make money, by selling the surplus electricity to the government. Moreover, because of the big bank of batteries, the cost of this project is fairly high. Figure 4-4 depicts the basic design of a grid tie system parallel with batteries.

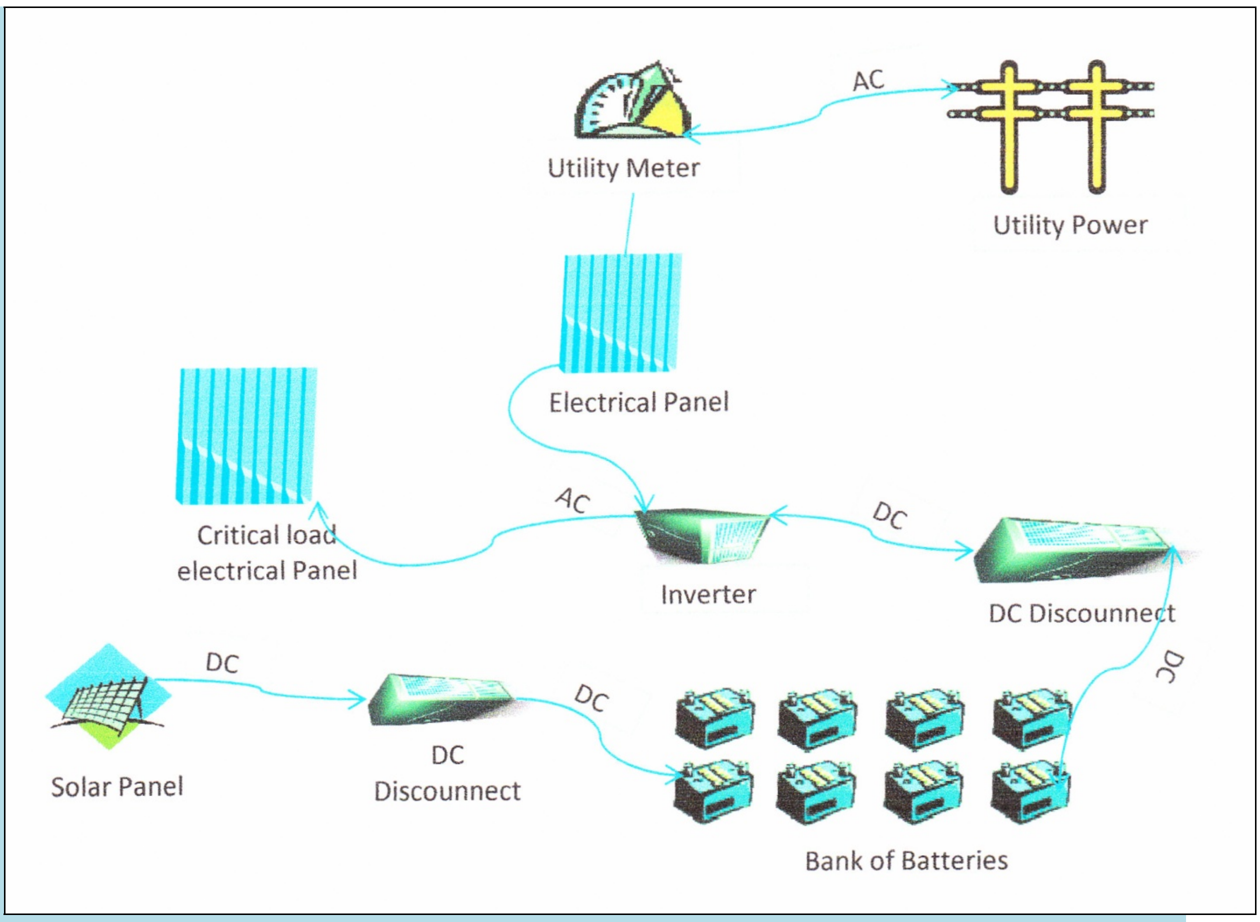


Figure 4-4, Grid ties parallel with batteries (Modified from Ewing, 2003)

4.3. Common Practices

Varieties of energy production have been invented to convert nature's energy into useable energy for daily applications. Many of these technologies are still in R&D centers and some of them are still not marketable. Among these entire technologies, solar water heaters, PV panels, and wind turbines are the most popular ones which are available on the market. In this section these three technologies are explained.

4.3.1. Solar Water Heaters

Solar water heaters are the technology which converts solar energy directly to heat energy. This is the device with the highest performance in converting energy. The mechanism is to trap solar energy in the solar panels and use it for heating another liquid.

There are 2 types of solar water panels. The best performance of each depends on climate.

4.3.1.1. Flat Solar Water Panels

This type of solar collector is more suitable for a moderate climate. As this kind of solar collector is not the best choice for a Canadian climate, information is provided briefly.

A liquid (water or glycol) circulates all over in the plate and absorbs the solar radiations. The absorbing plate is covered with Hi-Techs, layers of aluminum-nitrogen with aluminum base, which absorb solar energy to the maximum possible. Figure 4-5 shows a sample of a flat solar water heater.

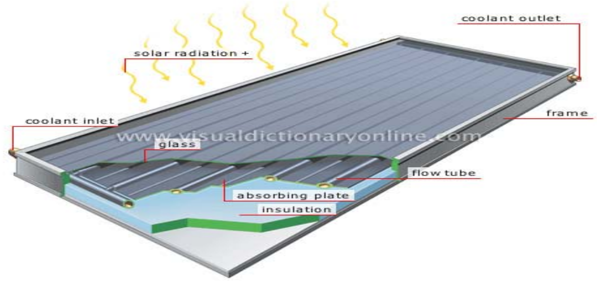


Figure 4-5, Flat solar panel (Visual dictionary, 2009)

4.3.1.2. Evacuated Tube Solar Water Panels

Evacuated tube solar collectors are designed more for cold climates like Canada because:

- the tubes are insulated by vacuuming the wind, and cold Canadian temperatures have minimal effect on the efficiency of the evacuated collector; work well on -60 degree below days;
- due to the cylindrical shape of the evacuated tube, the sun is perpendicular to the surface of the glass all day; this means that solar water heaters give the maximum output all day long; and
- by having a set of tubes, there is more surface to absorb solar energy, and as the surfaces are circular, absorbing the radiation is not limited just to one angle; solar energy is trapped in the tubes from all directions.

Figure 4-6, Tube solar panel (Courtesy of WSE Technology, 2009)

The physics behind tube solar heaters, according to the WSE technology website (2009), is: evacuated tubes are the main component of solar water heaters. Each of them is built up by two concentric glass pipes with thermal expansion of3.3 x 10-6 °C, the inner glass's outside surface tube is coated with layers of aluminum-nitrogen, which absorbs and converts the maximum amount (> 0.92, 80°C) of solar radiation, including infra red light, into heat. In this condition, radiation losses are very small (< 0.09, 80 °C). The gap between the outer and inner glass tubes is evacuated and eternally sealed off, permitting sunlight to go through perfectly while avoiding heat loss. Figure 4-7 illustrates the physical operations behind the tube.

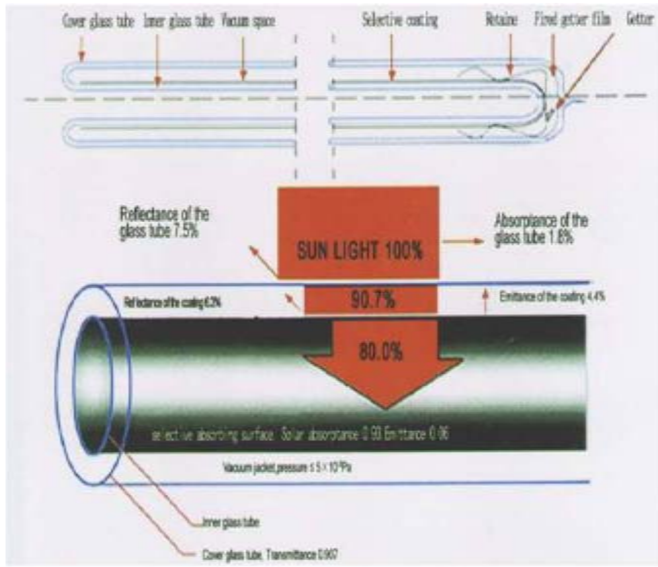


Figure 4-7, Tube solar panel’s operation (Courtesy of WSE technology, 2009)

Tube solar collectors are divided into categories. The regular solar collector model uses water as the circulation liquid. This kind of solar heater is good for using in the summer time, when the ambient temperature is not below zero. Usually the best application for this kind of solar water heater is heating the water in a swimming pool. The other type of solar collector uses pressurized tubes, where a copper core is inside of the inner tube and the circulation liquid is glycol. This works well in extreme cold weather. The application of pressurized tubes heats water all year round for showers, heating space or warming the garage. However, the price of pressurized tube solar collectors is double that of regular solar collectors.

Popular applications of solar water heater panels include:

- solar water heating systems for garage or shed;

- solar domestic water heating;
- solar heating whether radiator or floor heating;
- Solar heating commercial and warehouse buildings; and
- solar seating swimming pools, Jacuzzis or the like.

Figure 4-8 shows a complete system running by a solar water heater, consisting of all components to get the hot water heating system up and running. Below is an illustration showing the possible uses of the hot water. This application may not require all the heating zones shown, but this is an example of what a full blown heating system could do. It should be noted that this is a simplified diagram of an actual system.

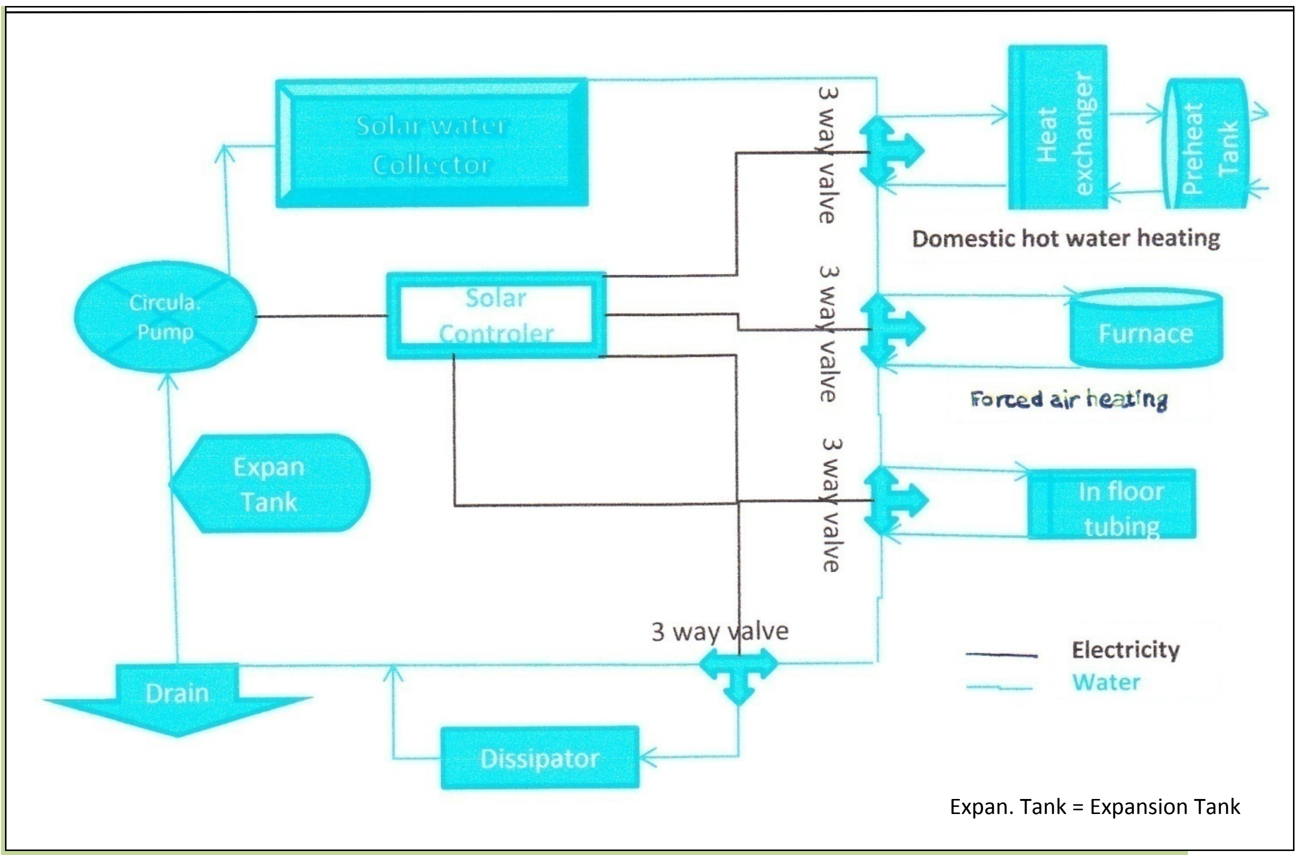


Figure 4-8, Running a complete system with solar water heaters (Courtesy: WSE Technology, 2009)

4.4. Photovoltaic (PV) Panels

Solar energy essentially comes from thermonuclear explosions as hydrogen atoms are fused into helium atoms. The energy resulted from this explosion is emitted into space through radiation; the sunlight we receive on the earth is the same radiation. The energy he sun donates to the earth each day is enough to meet earth's energy needs for an entire year. Photovoltaic (PV) is the technology that converts solar energy into electricity. PV makes use of renewable energy from the sun, and is a clean and environmentally sound means of collecting solar energy. The electricity coming from PV panels is DC. Solar cells are usually constructed with crystalline silicon that is used in the microprocessor industry, and more expensive gallium arsenide. The latter material is used exclusively for solar cells. Through depositing amorphous silicon alloy in continuous roll-to-roll processes, more efficient solar cells are manufactured. These kinds of solar panels are called Amorphous Silicon (A-Si), are more durable, efficient and thinner. The most recent technology is working at the quantum level to construct solar panels by converting carbon nanotubes or quantum dots into treated plastics. The main advantage of this method is the clean room can be eliminated and production costs are reduced drastically (Solar Panel info website, 2009). In Figure 4-9, a model of solar panel is illustrated.

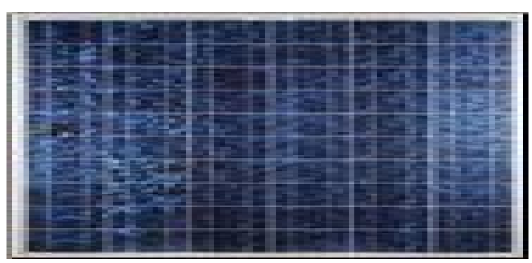


Figure 4-9, A PV Panel, SCM series 215W (REC Solar, 2009)

4.4.1. PV Panel Efficiency

There are a number of factors which affect PV solar panels' efficiency, the most important ones being:

1. ***Shade:*** PV solar panels function best when they are in direct sunlight. When the weather is cloudy or partially shady, the efficiency of PV panels is reduced. If

the shade covers more than 10 square cm, essentially the inner circuits of solar panel will not work and whole panel areas would be unable to create electricity.

2. ***Angle:*** PV solar cells function best when the panel makes right angles with the sun's rays. The angle of the mount of PV solar panels can be calculated by the following method (Ewing 2003):

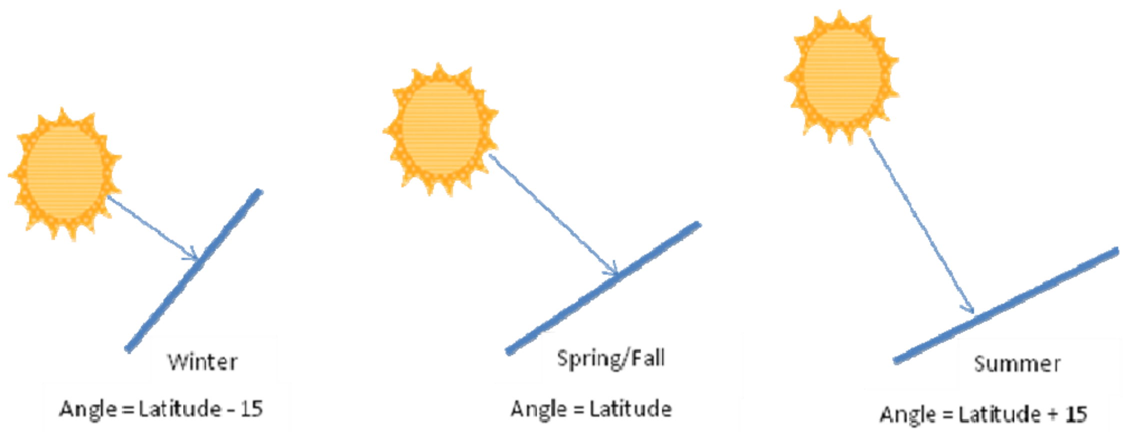


Figure 4-10, Seasonal tilt of the solar array (Adapted from Ewing, 2003)

3. ***Insulation:*** The amount of solar radiation absorbed by solar panels is considered as insulation. When the isolation is greater, the absorption of energy is higher and the amount of generated electricity is greater. Isolation depends on the geographic area and measures by kWh/m^2/d. In GTA isolation is 5.98 kWh/m^2/d in summer verses 1.08 kWh/m^2/d in winter.

4.5. Wind Turbines

Wind turbines are renewable energy that is capable of coming either in AC or DC form. Usually when the wind turbine is rated at 500 W or more, it generates 3-phase AC current. When there is an AC wind turbine and batteries are part of the design, there should be a special charge controller to convert the AC current to DC for charging the batteries. Moreover, when wind turbines are generating more power, they need to have a stronger foundation in the ground. This is an extra initial cost, plus the wind turbines should stay on that property; removing the installed wind turbines is not an easy process.

Wind turbines fall into two basic categories; the horizontal-axis variety, like the traditional farm windmills used for pumping water, and the vertical-axis design, like the vertical cylinder. In Figure 4-11-A, a typical vertical wind turbine is illustrated and in Figure 4-11-B, a horizontal wind turbine is depicted.

Figure 4-11-A A typical vertical wind turbine (courtesy of Eco Totally Life, 2009)

Figure 4-11-B A typical Horizontal wind turbine (Curtsey of Alert Idea, 2009)

4.5.1. Horizontal Wind Turbines

Horizontal wind turbines are more common than vertical wind turbines on the market. This type of wind turbine has a long history, and maybe this is the reason this type is more familiar to the public Greater detailed explanation about this kind of wind turbine is provided in the Design and Components section.

Wind turbines are a masterpiece of engineering; they are not limited just to mechanical engineering. Wind turbines are a complicated combination of deep aerodynamic, electrical engineering, mechanical engineering and safety engineering they even represent the foundation, to some extent, for civil engineering.

The reference for this section is from the Bonus-Info newsletter (1998). Each wind turbine has the main following components:

1. blades;
2. transmission system;
3. generator; and
4. tower.

4.5.2. Vertical Wind Turbines

Vertical-axis wind turbines are the younger generation and generate electricity with any direction of wind blow. This is the key advantage of vertical wind turbines. Based on Wikipedia, the vertical axis wind turbine was patented by Georges Jean Marie Darrieus in France. The gearbox and generator are usually installed close to the ground. This is another advantage in maintenance, but installation of the shaft and blades on the shaft is more challenging. Because of the design of the blades in vertical wind turbines, turbulence created under the blades causes vibration in the tower. This is not a disadvantage from a safety standpoint, but increases maintenance and reduces the service life of the turbines. Besides the technical issues over the turbulent flow of air, there is the noise issue for vertical wind turbines, which can be considered noise pollution for the environment.

The beauty of vertical wind turbines is the freedom in the variety of blade designs and combinations. For example 2, different designs of the blades are shown in Figure 4-12 and Figure 4-13.

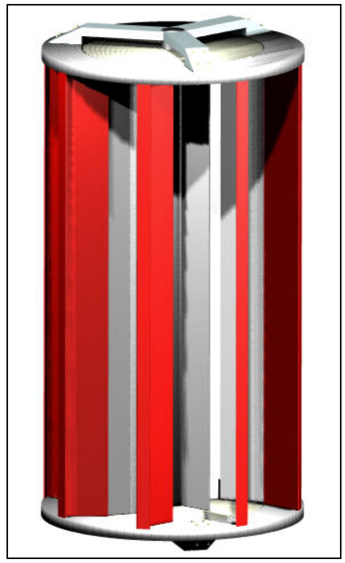


Figure 4-12, A schematic from the Zephyr blade design for a vertical wind turbine (courtesy of Zephyr Power, 2009)

Figure 4-13, A schematic from the conical blade design for a vertical wind turbine (courtesy of Poly Zero, 2009)

4.6. Geothermal Power

Geothermal energy system is the technology that extracts heat from the earth during winter and passes the building's heat back to the earth in the summer. This technology is also called the ground-source heat pump, and is based on the fact that the earth temperature is quite constant, about 6 °C (RETScreen 2005), approximately 1.5 m below the ground. By using a set of equipment (a compressor, an evaporator, an expansion valve and a heat exchanger), the earth's heat is exchanged with indoor air during demand time. In Canada, with its remarkable outdoor temperature fluctuations during the year, the geothermal energy system is a very effective technology.

The reference for this section is Natural Resources of Canada. A ground-source heat pump applies the earth or ground water as the source of heat in cold season, and acts as the "sink" for heat taken from indoors during the cold season. Heat exchange happens through an antifreeze liquid or ground water. All earth-energy systems have two parts:

I. an underground pipe circuit outside the house; and

II. a heat pump unit inside the house.

The underground piping system is either an open loop or closed system. And underground body of water is the heat reserve for an open system. The water is drawn directly from a well to the heat exchanger in order to release the heat. The water is then discharged to another well or to an above-ground water system. The closed loop system extracts heat from the ground through a loop of underground pipes. An antifreeze liquid, which has been chilled through the heat pump's refrigeration system, circulates inside the pipes and gathers heat from the soil. The fluid in a closed loop system circulates within the buried and pressurized pipe. The pipes' arrangement underground is either vertical or horizontal. A vertical closed loop piping is suitable for urban areas with restricted lot space. Pipes are inserted into bored holes which are approximately 150 mm in diameter to a depth of 18 to 60 m. Dimensions can be changed based on soil condition and system size. Generally, every ton of heat pump capacity (3.5 kW) demands 80 to 110 m of piping. A U-shaped loop is placed in each hole. The horizontal piping is more practical in rural areas, where there are larger properties. In this arrangement, pipes lay 1 to 1.8 m deep.

Usually, 120 to 180 m of pipe is needed for each ton of heat pump capacity. Figure 4-14 shows of a geothermal unit.

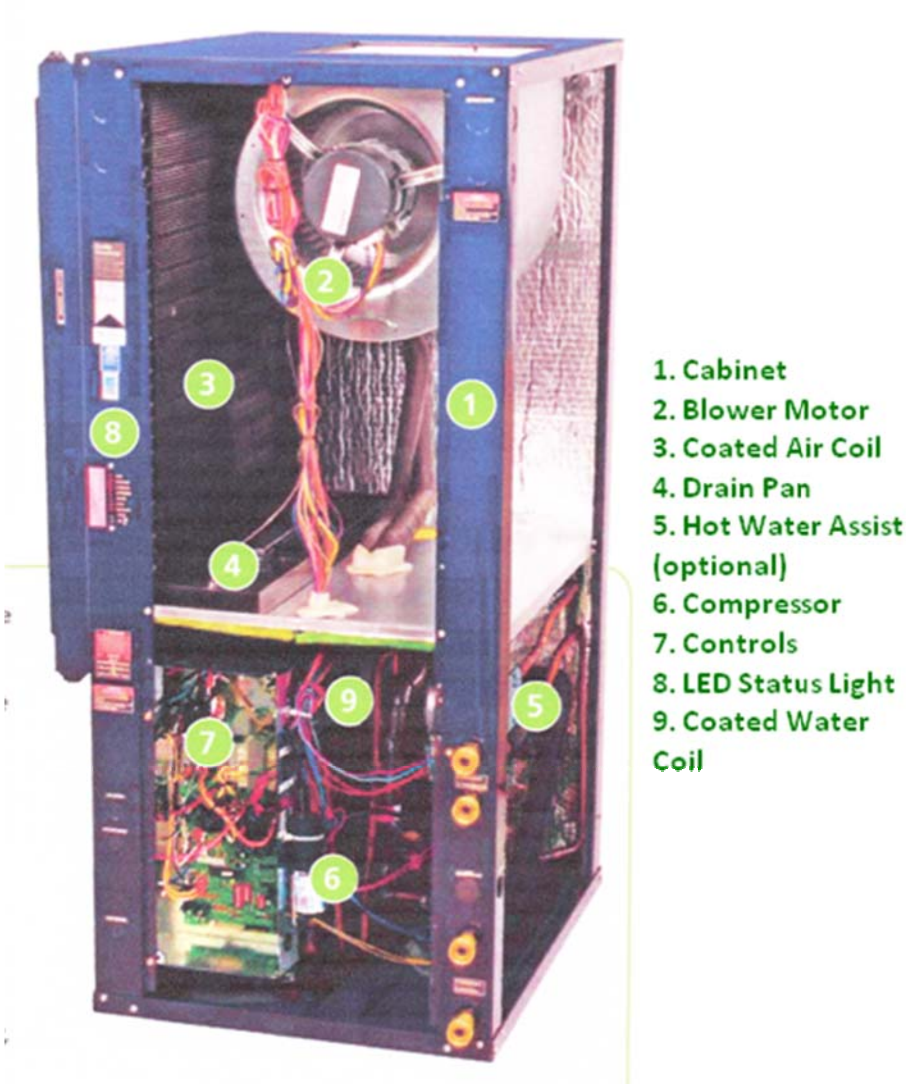


Figure 4-14, A view from a geothermal unit with main inside components (courtesy of Geosmart Energy, 2009)

Cabinet: The compact metal outer which holds all components inside. It is capable of absorbing the noise of components during their operation, is works quietly.

Blower Motor: The motor blows the air in the channels. It can be adjusted to different speeds and work quietly.

Coated air Coil: An air coil is coated to resist corrosion and increase the life of the equipment. When the air coil is coated, efficiency and dehumidification during the cooling cycle are both increased.

Drain Pan: This is a plastic part to prevent bacterial growth and removes the risk of condensate flooding through the applying electronic overflow production.

Hot Water Assist (Optional): This component preheats the domestic hot water. The more the unit works the more hot water it generates. In cooling mode, the waste heat is used to preheat the domestic water, and in heating mode, hot water generates at the efficiency of the unit.

Compressor: Used to compress the circulating fluid, ethanol, by drastically increasing the pressure.

Controls: High tech microprocessor control gives extreme performance. It also communicates with the thermostat, controls the compressor operation and troubleshoots the unit.

LED Status Light: These lights are mounted outside the unit as a guide to troubleshooting the system if a malfunction is indicated.

Coated Water Coil: The coaxial water coil guards the heat exchanger and is very much energy efficient.

4.6.1. The Heating Cycles

In the heating cycle, the circulating fluid gets heat from the soil and brings it to the heat pump unit. When the circulating fluid passes through the compressor, ~~as~~ high pressure, hot gas passes through the condenser; as indoor cold air passes through the condenser and heats up, it is blown as hot air through the house. The circulating liquid, after leaving its heat in the condenser, enters an expansion valve and leaves as cold liquid. This liquid passes through a spiral heat exchanger and back to the underground pipes to collect the ground heat and start another cycle.

In the heating cycle, a water coil can be installed between the compressor and the condenser to act as a dissipater to get extra heat to provide high temperatures and high pressure domestic hot water.

Figure 4-15 depicts a schematic picture of the ground source heat pump in the heating cycle.

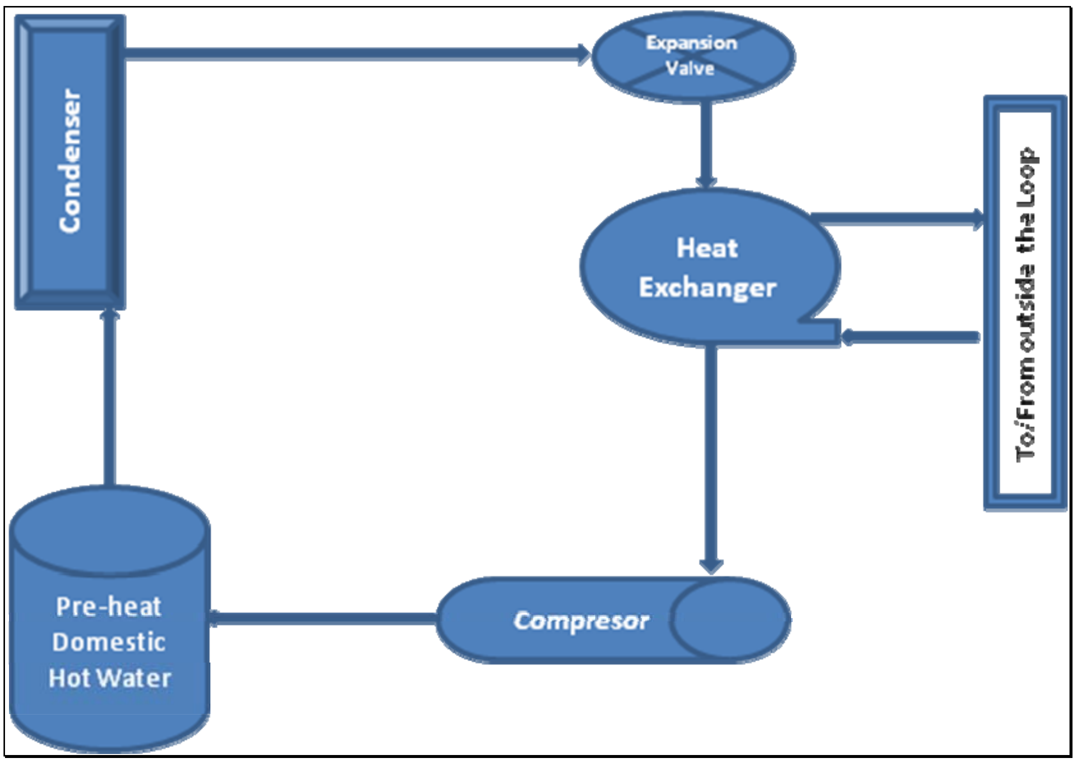


Figure 4-15, A schematic picture of the ground source heat pump in the heating cycle

4.6.2. The Cooling Cycles

Essentially, the cooling cycle is the reverse of the heating cycle, and the direction of circulating fluid is reversed. In this cycle, the circulating air or fluid gets the heat from indoor air and passes it to the ground. Also, some of this excess air can be used to preheat domestic hot water and has a positive effect on boiler efficiency.

4.6.3. Efficiency in Geothermal Energy System

With the ground-source heat pump, electricity is used to run the heat pump and the ground provides the energy for heating/cooling the building. By using efficient compressors and blowers, the energy to run the system is low ~~in~~ compared to work generated by the system, and could be as low as 25%. Earth energy systems with open loops have heating COP ranging from 3.0 to 4.0, and a COP range for cooling cycles of 11.0 to 17.0. When the heat pump is working in a closed loop system, the COP for the heating system is between 2.5 and 4.0, while the COP for the cooling system is 10.5 to 20.0. By improving the technology in manufacturing the components of heat pumps, the efficiency of the system increases.

4.7. Comparison of Geothermal Energy to Wind and Solar Energy

As mentioned previously, the earth's temperature is quite constant, and is always accessible through ground source energy heat pumps. Therefore, geothermal energy is a reliable source of energy. However, wind energy and solar energy do fluctuate daily and to use wind and solar technology, a backup system should be considered.

Geothermal technology has higher installation costs compared to the cost of wind and solar projects. In some smaller projects, there are no installation costs.

4.8. Comparison of Wind Turbine and PV Panels

Installation costs for wind turbines are higher than for PV panels. Dismantling wind turbines is a difficult process and in some cases impossible. They cannot be installed in urban areas and definitely need a piece of land in the countryside for installation. However, the electricity generated by wind turbines is cheaper.

PV panels are portable and easily dismantle for moving to another property. PV panels are very user friendly, and can be installed on roofs or walls. PV panels do not demand a large piece of land. Moreover, based on bylaws, PV panels can be installed in urban areas. However, there must not be any shade in the installation area.

4.9. Summary

To switch to renewable energy, the first decisions in going completely grid free, or to some extent, being dependent on the grid, are design criteria and local circumstances. Off grid and grid tie systems have their own advantages and disadvantages, as explained, and the grid tie system itself has three different types. Budget and performance determine which grid tie system is the best fit for the project.

Solar water collectors are the most efficient solar equipment which converts solar energy into useful energy for humans. Solar collectors are categorize as flat panels, which are suitable for moderate climate conditions, and tubes collectors which are a good fit for cold climates. Solar collectors can be used for heating the water and space.

Getting electricity from the sun is solely through PV panels. PV panels are very useful for humans since previous decades. The luxury of PV panels has allowed man the ability to travel through space and use solar energy as a source of power in space. Satellites in space are all equipped with PV solar panels.

Wind turbines are another technology which converts natural energy to electricity. From another point of view, wind turbines are a masterpiece of human intelligence that is the combination of engineering and science. Wind turbines are the result of electrical engineering, mechanical engineering, aerodynamics, and safety engineering. Mainly wind turbines are categorized as horizontal and vertical wind turbines.

The ground source heat pump is another technology used to convert the earth's energy into heat. This technology is very reliable and efficient.

Electricity coming from PV panels and wind turbines can be compared in different aspects, each of them having its own benefits. Depending on project requirements, individually or in combination they can be considered as a source of natural energy.

Chapter 5: Analysis of Renewable Energy Technology Systems

5.1. Introduction

In this chapter, the details of the calculation for renewable energy are described. Calculations for PV panels' arrays in different methods, and the most popular one for the grid time system, are given in detail. The actual application of these equations is explained in Chapter 6, Case Studies. The calculation for wind turbines is clarified as well. However, because of the nature of the case studies, wind turbine equations are not used in this thesis. The financial calculations are elaborated upon in two equations, first, the "future value" equation which shows the value of money in the future, and secondly, the "mortgage formula" equation which is a tool to calculate monthly payment of a loan. The financial equations are used in Chapter 6 for each case study in the cost analysis section.

5.2. PV Array Calculation Methods

There are different methods of calculating solar arrays. The first method is more detail oriented and practical for the real cases of PV panels than the second method, which is for fast calculation of PV panels. Both methods are described in the following paragraphs.

5.2.1. Method 1

All methods have the same principle; however, there are some differences in detail. The methods shown here are explained in Alert Idea's website.

Step 1: Finding the monthly average electricity usage from the electricity bill.

This will be in kilowatt-hours (kWh). Due to air conditioning, heating and other seasonal usage, it is a good idea to look at several bills. The best practice is to add the typical summer, fall, winter and spring bills, and then divide by four to find the average monthly usage.

Step 2: Finding the daily average electricity use.

Divide the monthly average number of kWh use by 30 (days).

Step 3: Finding the location's average peak sun hours per day.

This formula finds the isolation coefficient of the area. For example, for Toronto the formula is 1.08 $kWh/m^2/dkWh/m^2/d$ in winter.

Step 4: Calculating the system size (AC watts) to provide 100% of the electricity.

Divide the daily average electricity use by the average sun hours per day. For example, if the daily average electricity use is 30 kWh, and the site is in Toronto, the system size would be: 30 kWh / 3 h = 10 kW AC. (Multiply kWh by 1000 to get AC watts.)

Step 5: Calculating the number of PV modules required for this system.

Divide the system AC watts in Step 4 by the CEC watt rating of the modules to be used, and then divide by the inverter efficiency, usually 0.94, to get the total number of modules required. (Round this number up)

5.2.2. Method 2

The beauty of this method is its simplicity. One is able to find the answer quickly and easily.

Step 1: Finding the highest electricity usage from the electricity bill.

This is in kilowatt-hours (kWh). Due to air conditioning, heating and other seasonal usage, it is a good idea to look at an entire year's bills to find the highest electricity consumption. Usually, in hydro bills, it shows the average electricity consumption per day. The highest one should be chosen.

Step 2: Finding the hourly electricity usage.

Divide the maximum daily usage by 24 hours. This gives you the hourly usage. This is the power that solar energy should provide.

Step 3: Finding the quantity of PV panels.

The number of PV panels results from dividing the maximum hourly consumption by the power of chosen PV panel.

5.3. Geothermal Energy System Calculations

Geothermal energy calculations are quite complicated. Before starting the calculations, some assumptions are considered as a road map for following the equations. Further information on this section is found in reference (RETScreen 2005, Ground-Source Heat Pump Project Analysis Chapter.)

This model primarily sets up the building load equation, which explains how building loads fluctuate as a function of outside temperature. The software then calculates the load for each temperature bin. Applying the building load equation, balance point temperatures are calculated to establish whether heating or cooling is required for each bin. By using the weather data and the building load, the required capacity of the heat pump is estimated; this allows the sizing of the ground loop. Knowing this, the real heat pump performance and capacity are calculated for each bin. The ultimate results come from the model including the yearly electricity consumption of the heat pump system, the heating and cooling energy system efficiencies and any back-up heating energy conditions.

5.3.1. Bin Method and Design Condition

The bin method has been applied for many years to guesstimate energy consumption by buildings (ASHRAE Handbook, Fundamentals, 1981, 1985). In the temperature frequency method, the annual hours with the same temperature are totalled into a finite number of bins according to temperatures. Each bin symbolizes the average of the temperature range for that bin. By applying the bin method, it is possible to calculate the ground source heat pump building system temperature dependant routine and even dependant parameters, and then estimate the system's energy consumption in that year.

For this calculation, day and night time bin temperature should be available. Moreover, bin information for the coldest and hottest months is needed for the ground loop calculation. An hourly weather data generator is included in the RETScreen. Also, ground temperature is applied in the model to assess residential building basement heat losses.

The undisturbed temperature of ground, T_g expressed in °F, can be calculated by (IGSHPA, 1988):

$$T_g\,(X_g, t) = \overline{T_g} - A_s \exp\left(-X_s \sqrt{\frac{\pi}{365\alpha}}\right) \cos\left(\frac{2\pi}{365\alpha}\left[\,t - t_0 - \frac{X_2}{2}\sqrt{\frac{365}{\pi\alpha}}\right)\right. \qquad (5\text{-}1)$$

where X_s X_s is the depth of the soil (feet) , t is the day of year, $\overline{T_g}$ is the annual average surface soil temperature, A_s is the yearly surface temperature, equal to $(T_{max} - T_{min})$, t_0 is a constant expressed in days, and α is the soil thermal diffusivity. α is calculated as follow:

$$\alpha = {}^{k}/_{\rho}\ C_P \qquad (5\text{-}2)$$

where k is the thermal conductivity in BTU/hr lb °F, ρ ρ is the density in lb/cube ft and C_P is specific heat in BTU/lb °F.

By using equation (5-1), the minimum and maximum temperatures of the ground for any depth can be calculated as:

$$T_{g,min} = \overline{T_g} - A_s \exp\left(-X_s \sqrt{\frac{\pi}{365\alpha}}\right) \qquad (5\text{-}3)$$

$$T_{g,max} = \overline{T_g} + A_s \exp\left(-X_s \sqrt{\frac{\pi}{365\alpha}}\right) \qquad (5\text{-}4)$$

Average depth for compound horizontal heat exchanger pipe systems and shallow vertical boreholes, X_s can be calculated by equations (5-1) to (5-4). In vertical piping systems, this is usually a minor task since the beneath surface, ground temperature is almost constant all year (Kavanaugh and Rafferty, 1997); ground temperature is considered the mean annual surface soil temperature, $\overline{T_g}$.

5.3.2. Building Load Calculation – Descriptive Data Method

There are two methods of modeling a ground source heat pump project: the energy method or descriptive data method. The energy method uses typical energy consumption of the building, however, in the descriptive data method; the characteristic of the building is the main source of information for modeling. This section is dedicated to the descriptive data method.

In this model a residential building is considered as a "block load". A block load is the maximum load in a building at a certain time under design temperature conditions.

The effects of outside temperature and different building heating and cooling load components is considered, as explained in the "modified bin method" ASHRAE (1985). The main factors are:

Transmission losses (conductive and convective);

- solar gains (sensible);
- fresh air loads (latent and sensible);
- internal gains (latent and sensible); and
- occupant loads (latent and sensible).

All loads are categorized as a polynomial of zero, first or second order, as presented in the following basic equations 5-5, 5-6 and 5-7:

$$q_j = c_{0,j} \tag{5-5}$$

$$q_j = c_{0,j} + c_{1,j}\, T_0 \tag{5-6}$$

$$q_j = c_{0,j} + c_{1,j}\, T_0 + c_{2,j}\, {T_0}^2 \tag{5-7}$$

where the building load is q_j from source *j* (e.g. transmission losses, solar gains, fresh air, internal gains, and occupant loads), T_0 is the outside air temperature, and $c_{0,j}$, $c_{1,j}$ and $c_{2,j}$ are polynomial coefficients obtained from physical building characteristics linked to source j.

Basements have a heat loss effect, especially in residential buildings. This impact is considered by the following equation:

$$q_k = d_{0,k} + d_{1.k}\, T_g \tag{5-8}$$

Where q_k stands for the building load from below-grade component *k*, T_g is the temperature of the ground surrounding the basement and $d_{0,k}$ and $d_{1,k}$ are coefficients of the polynomial obtained from the physical characteristics of the building for each below-grade component *k*.

The total building load equation as a role of outside air temperature and ground temperature is then obtained through a summary of all *n* above-grade and *m* below-grade load components as follow:

$$q_{tot} = \sum_{j=1}^{n} c_{0,j} + \sum_{j=1}^{n} c_{1,j} T_0 + \sum_{j=1}^{n} c_{1,j} T_0^2 + \sum_{k=1}^{m} d_{0,k} + \sum_{k=1}^{m} d_{1,k} T_g \quad (5\text{-}9)$$

This equation is written quickly as:

$$q_{tot} = c_0 + c_1 T_0 + c_2 T_0^2 + d_0 + d_1 T_g \quad (5\text{-}10)$$

where each c_i and d_i d_i is the total of all $c_{i,j}$ or $d_{i,k}$.

5.3.2.1. Transmission Losses (Conductive & Convective)

Conductive and convective transmission losses for a building are calculated by:

$$q_{trans} = \sum_i (UA)_i \, (T_0 - T_{in}) \quad (5\text{-}11)$$

UA_i ( ) is the global heat transfer coefficient of exterior component, *i* and T_{in} are the inside temperature. By combining this equation with equation (5-6), the following equation can be obtained:

$$c_0 = -\sum_i (UA)_i \, (T_{in}) \quad (5\text{-}12)$$

$$c_1 = \sum_i (UA)_i \quad (5\text{-}13)$$

Above-grade losses: Wall height is considered 2.5 m. If the basement is full, assumption of the modeling is the height $H_{f,0}$ = 0.7 m of the foundation wall is out in the open to outside air. The model assumes that the building has a square footprint; therefore the perimeter of the building is 4 *S Z* where *S* is the total floor area and *Z* is the number of floors. Finally, the global heat transfer coefficient for that becomes:

$$UA = U_{f,wall} \, 4 Z H_{f,0} \sqrt{S/Z} \quad (5\text{-}14)$$

where $U_{f,wall} U_{f,wall}$ is the "U-value" for foundation walls. The model assumption for a slab on grade foundation is roughly half the slab area where it is in contact with outside air, the rest is in contact with ground temperature, then:

$$UA = U_{f,floor} \, \frac{1}{2} \frac{S}{Z} \quad (5\text{-}15)$$

where $U_{f,floor}$ is the "U-value" for the basement floor.

Below-grade losses: The method for calculating below-grade foundation heat losses is very similar to the method used in the low-rise residential energy analysis and design software HOT2000TM (1991). The full basement below-grade component losses are categorized in four parts:

- upper below-grade wall, representing around 1/3 of the below-grade height;
- lower below-grade wall, representing the rest of 2/3 of the below-grade height;
- floor perimeter area, is assumed half the floor area; and
- floor centre area, is assumed half the floor area.

Transmission losses are similar to (5-11), only outside air temperature is changed by ground temperature:

$$q_{trans,g} = \sum_i (UA)_i \left(T_{in} - T_g\right) \tag{5-16}$$

As the bin method only presents air temperature distribution, a linear correlation between the outside air temperature and the ground temperature is applied to express the ground temperature for each bin:

$$T_g = T_{g,max} + \frac{(T_{g,min} - T_{g,max})}{(T_{d,heat} - T_{d,cool})} \left(T_{bin} - T_{d,cool}\right) \tag{5-17}$$

where T_{bin} is the bin temperature. d_0 and d_1 are coefficients, and are calculated for each below-grade components for below-grade walls (full foundation):

$$d_0 = -4\, U_{f,wall} \sqrt{\frac{S}{Z}}\, H_{f,g}\, T_{in} \tag{5-18}$$

$$d_1 = 4\, U_{f,wall} \sqrt{\frac{S}{Z}}\, H_{f,g} \tag{5-19}$$

and for below-grade floor (full foundation):

$$d_0 = -\, U_{f,floor} \frac{S}{Z}\, T_{in} \tag{5-20}$$

$$d_1 = U_{f,floor} \frac{S}{Z}\, H_{f,g} \tag{5-21}$$

For slab on grade foundations, only half of the last two equations are utilized.

5.3.2.2. Solar Gains (Sensible)

Solar gains through windows express a method to find the relationship similar to equation (5-6). In the bin method, the assumption is based on a linear relationship between outdoor temperature and solar gains in a building. Then solar gains through windows are as follows:

$$q_{sol} = S_c[q_{sol,winter} + M(T_a - T_{ph})] \tag{5-22}$$

which can be reordered like equation (5-6) as follow:

$$c_0 = S_c(q_{sol,winter} - MT_{ph}) \quad (5\text{-}23)$$

$$c_1 = S_c M \quad (5\text{-}24)$$

In the above equations, S_c stands for the building conditioned floor area, and *M* represents the solar heat gain interpolation coefficient, as:

$$M = \frac{(q_{sol,summer} - q_{sol,winter})}{(T_{pc} - T_{ph})} \quad (5\text{-}25)$$

where $q_{sol,winter}$ and $q_{sol,summer}$ are the average solar input for winter and summer for the location of the building , T_{hc} and T_{pc} are heating and cooling design day average temperatures. The design day average temperatures are calculated from the heating and cooling design day temperatures $T_{d,heat}$ $T_{d,heat}$ and $T_{d,cool}T_{d,cool}$ which are specified by the user.

$$T_{pc} = T_{d,cool} - DR/2 \quad (5\text{-}26)$$

$$T_{ph} = T_{d,heat} + DR/2 \quad (5\text{-}27)$$

where *DR* is the average daily temperature range and is specified by the user. The computation for the winter and summer mean solar gain is based on the ASHRAE's Cooling Load Factor (CLF) method (see ASHRAE, 1985, ch. 26). Finally, by applying this method, the solar gain is:

$$q_{sol,season} = \frac{\sum_{ori} MSHGF_{ori,season} AG_{ori}\, SC_{ori}\, CLF_{tot,ori}\ FPS_{season}}{nh_{season} S_C} \quad (5\text{-}28)$$

where *ori* is the orientation (north, east, south, west is considered in the ground source heat pump Project Model), *season* stands for the warmest or coolest month (e.g. January or July in the northern hemisphere), $MSHGF_{ori,season}$ represents the maximum solar heat gain factor for orientation *ori* and month *season* at the building's latitude, AG_{ori} stands for the glass area for exposure *ori* , SC_{ori} represents the shading coefficient of glass for contact *ori* , $CLF_{tot,ori}$ represents the 24-hour sum for the cooling load factors of orientation *ori* , FPS_{season} stands for the fraction of potential sunshine for the *season,* nh_{season} represents the number of working hours of air conditioning for the *season*, and *Sc* represents the building conditioned floor area. Lastly, glass area on all orientations is supposed to be equal to 1/4 of the total glass area *AG* for each of the four orientations. By applying all parameters in equation (5-28), that equation becomes:

$$q_{sol,season} = \frac{AG\ SC_{ori} FPS_{season}}{4\ nh_{season} S_c} \sum_{ori} (MSHGF_{ori,season} CLF_{tot,ori}) \qquad (5\text{-}29)$$

5.3.2.3. Internal Gains (Sensible)

The treatment for the sensible internal gains is not complicated. All internal sources of gains are considered free from outside temperature. Then the equation of internal gains by considering equation (5-5) can be defined as:

$$c_0 = K_{int} + K_{\rho,sens} \qquad (5\text{-}30)$$

where K_{int} is gains from all equipment, lights and appliances, and $K_{\rho,sens}$ stands for gains from residents. The constants in equation (5-30) are considered 14 W/sq m for internal gains, and 74.6 W/person for residents (ASHRAE, 1985). The model assumption is two adults and two children in the building at all times; the mean heat gain from children is half that of an adult.

5.3.2.4. Fresh Air Load (Sensible)

The load of outside air entering the building is calculated proportionate to the number of residents in the building. This load is shared between sensible and latent components. The basic equation for computing the sensible load $q_{f,sens} q_{f,sens}$ for outside air stream is:

$$q_{f,sens} = \rho\ C_p\ \dot{V}(T_{in} - T_0) \qquad (5\text{-}31)$$

where ρ is air density, $C_p\ C_p$ is air specific heat, and $\dot{V}\dot{V}$ is the volumetric flow rate of incoming air. This equation is rearranged to the basic form of equation (5-6) as:

$$q_{f,sens} = c_0 + c_1 T_0 \qquad (5\text{-}32)$$

by:

$$c_0 = \rho\ C_p\ \dot{V} T_{in} \qquad (5\text{-}33)$$

$$c_1 = \rho\ C_p\ \dot{V} \qquad (5\text{-}34)$$

For the model air density, specific heat is considered constant values (ρ = 1.2 kg/m2, *Cp*=1.005 (kJ/kg)/°C). The quantity of fresh air coming into the building is considered 20 L/s/person, half of this is heat exchange between outside air stream and the indoor air. Consequently, the net effective airflow per resident is reduced to 10 L/s for thermal balance computations.

Nonetheless, the amount of fresh air entering a residential building is not correlated to the number of residents, rather to the level of insulation pointed to qualitatively by the user, the better the insulation level the smaller the quantity of air incoming into the building. The number of air changes in each hour (ACH), is related to insulation level; ACH is 0.5 for low, 0.25 for medium and 0.1 for high insulation level, Hydro-Québec, (1994).

The volume of the house is computed by using $HS + H_b\, {}^{S}/_{Z}\; HS + H_b\, {}^{S}/_{Z}$ when *H is* the estimated wall height (about 2.5 m), H_b is the basement height (about 2.2 m, when there is any), *S* is the floor area (not including the basement) and *Z* is the number of stories.

5.3.2.5. Fresh Air Load (Latent)

The latent load has an effect only on air-conditioning. In the modeling of a ground source heat pump, no humidifier is considered during heating season. To calculate the wet bulb temperature of the entering air, the conventional method of computing an outside air latent load is applied. By using the water content and the enthalpy of saturated water vapour, the equation of latent load $q_{f,lat}$ is:

$$q_{f,lat} = \rho\dot{V}(W_0 h_{g,0} - W_{in} h_{g,in}) \tag{5-35}$$

where *W* stands for the air water content, the enthalpy of saturated water vapour is $h = 2501 + 1.805\, T_{air}$ and T_{air} represents the air temperature; "o" and "in" denote outside and inside air. The project location's humidity level should be specified. The highest fraction of latent load, *f,* to sensible load is identified as a function of the specified qualitative data. The maximum latent to sensible fraction is 0.5 for low, 1.5 for medium and 2.5 for high humidity level.

The mathematical formulation for *f,* the fraction of latent to sensible load, is:

$$f = aT_0 + b \qquad \textit{for } T_0 > 10°C \tag{5-36}$$

$$f = 0 \qquad \textit{for } T_0 < 10°C \tag{5-37}$$

where *a* and *b* are calculated from highest latent to sensible fraction f_{max}. Also, from summer design temperature $T_{d,cool}$ through:

$$a = \frac{f_{max} - f_{min}}{DT} \tag{5-38}$$

$$b = f_{min} - \left(\frac{T_{d,cool} - DT}{DT}\right)(f_{max} - f_{min}) \tag{5-39}$$

The valid latent load is calculated by multiplying equations (5-36), (5-37), and equation (5-31) for the sensible load. The resulting equation is a second order polynomial, like equation (5-7):

$$q_{f,lat} = c_0 + c_1 T_0 + c_2 T_0^2 \tag{5-40}$$

through:

$$c_0 = b\rho C_p \dot{V} T_{in} \tag{5-41}$$

$$c_1 = a\rho C_p \dot{V} T_{in} - b\rho C_p \dot{V} \tag{5-42}$$

$$c_2 = -a\rho C_p \dot{V} \tag{5-43}$$

All variables were already characterized.

The calculation of the airflow rate is the same method as explained in section 5.4.2.4.

5.3.2.6. Internal Gains (Latent)

For calculating sensible internal gains, latent internal gains are considered constant. Only latent internal gains from residents are assumed in the model. As a result, the equation for latent internal gains $q_{int,lat}$ is zero order polynomial, same as equation (5-5):

$$c_0 = K_{p,lat} \tag{5-44}$$

where $K_{p,lat}$ stands for constant latent gains from residents. This constant is equal to 74.6 W/occupant (ASHRAE, 1985). The computation method is explained in section 5.4.2.3.

Residential building load equation and balance points: After calculating all load components (5.4.2.1 to 5.4.2.6), by replacing c_0, c_1, c_2, d_0 and d_1 coefficients into equation (5-9), the building energy load is calculated. This calculation is for four sets of coefficients, daytimes, nighttimes, cooling and heating conditions.

The optimum temperature T_{bal} can be found as the root of equation (5-9):

$$T_{bal} = \frac{-c_1 \pm \sqrt{c_1^2 - 4c_2(c_0 + d_0 + d_1 T_g)}}{2c_2} \quad (5\text{-}45)$$

Equation (5-45) is simplified by removing the quadrant assumption for the coefficients, as:

$$T_{bal} = \frac{-c_0 + d_0 - d_1 T_g}{c_1} \quad (5\text{-}46)$$

5.3.3. Building Load Calculation – Energy Use Method

The descriptive data method for building load calculation (section 5.4.2) is practical for a new building. Moreover, this method may not be suitable for commercial and industrial buildings which are further compounded. Another method is to specify known building energy - to be precise, the building's energy consumption per year and the building's design loads. Through this data, an equation comparable to equation (5-6) is obtained. This approach is called the "energy use method". In this section, the energy use method is explained.

The leading equation in this method is:

$$q_{d,heat} = c_0 + c_1 T_{d,heat} \quad (5\text{-}47)$$

where $q_{d,heat}$ is the design heating load, and $T_{d,heat}$ is the heating design temperature. This equation is defined in discrete structure as:

$$q_{tot,heat} = \sum_{i=1}^{p} \left(c_0 + T_{o,i}\right) h\, T_{o,i} \quad (5\text{-}48)$$

where $T_{o,i}$ stands for the mean temperature for each of the *p* bins on hand in the model (1≤*i*≤*p*), and *h* $(T_{o,i})$ is the hours of incident of outside temperature $T_{o,i}$ during the heating season. Equations 5-47 and 5-48 make up a simple set of two equations include two unknowns, c_0 and c_1. Then by solving this set of equation unknown will be express as follows:

$$c_0 = \left[\frac{q_{d,heat} \sum_{i=1}^{p} T_{o,i}\, h(T_{o,i}) - q_{tot} T_{d,heat}}{\sum_{i=1}^{p} T_{o,i}\, h(T_{o,i}) - T_{d,heat} \sum_{i=}^{p} h\,(T_{o,i})}\right] \quad (5\text{-}49)$$

$$c_1 = \left[\frac{q_{tot} - q_{d,heat} \sum_{i=1}^{p} h(T_{o,i})}{\sum_{i=1}^{p} T_{o,i}\, h(T_{o,i}) - T_{d,heat} \sum_{i=}^{p} h\,(T_{o,i})}\right] \quad (5\text{-}50)$$

To calculate the coefficients defined in equations (5-49) and (5-50), only the temperature bins matching to a heating load are considered. These bins are those related to temperatures below the optimum temperature.

5.3.4. Building Load Calculation for each Temperature Bin

Through either the descriptive data method or the energy use method, the building load for each bin temperature is calculated (equation (5-9)). These results lead to the optimum temperature (balance point temperature).

5.3.5. Earth Connection - Closed-Loop Ground Heat Exchangers

Sizing the ground heat exchanger primarily demands the length of the heat exchanger length. The approach for finding the heat exchanger length is modified from IGSHPA (1988). Based on heat requirements, the ground heat exchanger length L_h is:

$$L_h = q_{d,heat}[\frac{\frac{(COP_h - 1)}{COP_h}}{T_{g,min} - T_{gwt,min}} \left(R_p + R_s F_h\right)] \tag{5-51}$$

where COP_h stands for the design heating coefficient of performance, COP_h is the heat pump system, R_p represents the thermal resistance of the pipe, R_s stands for the soil/field thermal resistance, F_h represents the ground heat exchanger part load factor for heating , $T_{g,min}$ represents the lowest undisturbed ground temperature, and $T_{gwt,min}$ is the design incoming water temperature (EWT) at the heat pump. A similar equation is applied for computing the ground heat exchanger length *Lc* derived from cooling conditions:

$$L_c = q_{d,heat}[\frac{\frac{(COP_c + 1)}{COP_c}}{T_{g,max} - T_{gwt,max}} \left(R_p + R_s F_c\right)] \tag{5-52}$$

where COP_c stands for the design cooling coefficient of performance (*COP*) for the heat pump system, F_c represents the part load factor for cooling, $T_{g,max}$ is the highest undisturbed ground temperature, and $T_{gwt,max}$ is the highest design incoming water temperature at the heat pump. These two equations characterize an overview of the ones developed by Ingersoll and presented in Kavanaugh and Rafferty (1997).

5.3.6. Heat Pump System

The computations of these elements are essential to complete the earth connection sizing for closed-loop ground heat exchangers. The heat pump coefficient of performance (*COP*), and related capacity (*Qc/h*) is primarily calculated, and the heat pump's incoming water temperature is obtained.

5.3.6.1. Coefficient of performance (COP) and capacity ($Q_{c/h}Q_{c/h}$)

The coefficient of performance (*COP*) for a heat pump system is correlated to the entering water temperature, Tarnawski (1990). The ground heat exchanger load and heat pump capacity are connected by:

For cooling:

$$Q_c = Q_{he,c} \frac{COP_c}{COP_c + 1} \tag{5-53}$$

For heating:

$$Q_h = Q_{he,h} \frac{COP_h}{COP_h - 1} \tag{5-54}$$

where Q_c stands for the heat pump cooling capacity for the evaporator, $Q_{he,c}$ represents the heat rebuffed to the ground heat exchanger for the heat pump condenser in cooling mode, Q_h stands for the heat pump heating capacity for the condenser, and $Q_{he,h}$ represents the heat obtained from the ground heat exchanger for the heat pump evaporator in heating mode.

The approach to model the *COP* and the capacity as a function of temperature of entering fluid applies a quadratic polynomial correlation:

$$COP_{actual} = COP_{baseline}(k_0 + k_1 T_{ewt} + k_2 T_{ewt}^2) \tag{5-55}$$

$$Q_{c/h} = \chi\,(\lambda_0 + \lambda_1 T_{ewt} + \lambda_2 T_{ewt}^2) \tag{5-56}$$

where COP_{actual} stands for the actual COP of the heat pump, $COP_{baseline}$ represents the nominal *COP* of the heat pump, $Q_{c/h}$ stands for the capacity of the heat pump for cooling or heating, and then k_i and λ_i represent correlation coefficients. And last, χ stands for a capacity multiplier, obtained for the system to cover either the building's heating or cooling load.

For the cooling load design criteria, the heat pump's capacity is picked according to demand essential to cover the cooling load. If there is a need for extra heating capacity, the model assumes an accessible backup heat source. The backup heat or auxiliary heat then has equivalent efficiency and energy source similar to the base case heating, ventilation, and air conditioning system identified by the user. Then the capacity multiplier χ is:

$$\chi = \frac{q_{d,cool}}{(\lambda_0+\lambda_1 T_{ewt,max}+ \lambda_2 T_{ewt,max}^2)} \tag{5-57}$$

where $q_{d,cool}$ stands for the design cooling load and $T_{ewt,max}$ represents the highest temperature of entering water as already mentioned.

When heating is the design criteria, the capacity multiplier χ is the greater value of equations (5-57) or (5-58):

$$\chi = \frac{q_{d,heat}}{(\lambda_0+\lambda_1 T_{ewt,min}+ \lambda_2 T_{ewt,min}^2)} \tag{5-58}$$

where $T_{ewt,\min}$ represents the lowest temperature of entering water as already explained. The highest value of the capacity multiplier χ results from equations (5-57) or (5-58) and is preserved since model assumption is that cooling requirements must be covered by the installed heat pumps.

5.3.6.2. Entering water temperature (Tw,i) for closed-loop ground exchanger

To estimate the heat pump coefficient of performance (*COP*) and correlated capacity (*Qc/h*) for all temperature bins, a linear interpolation approach was obtained according to IGSHPA (1988). For a specified bin temperature $T_{bin,i}$, the temperature $T_{w,i}$ of entering water into the heat pump is then:

$$T_{w,i} = T_{min} + \left(\frac{T_{ewt,max}- T_{ewt,min}}{T_{d,cool}- T_{d,heat}}\right)(T_{bin,i} - T_{d,heat}) \tag{5-59}$$

where T_{min} is the least temperature of the entering water with other variables already been defined.

5.3.7. Energy Use Evaluation

The energy use evaluations obtained in this section is focused on the energy consumption by backup pumps which serve to cover the heating or cooling loads that are not met by the ground source heat pump system.

5.3.7.1. Heat pump run time and energy use of backup pumps

Based on theories Run Time of a heat pump can be obtained for each temperature bin as:

$$Run\ Time = \frac{q_{tot}}{Q} \tag{5-60}$$

where q_{tot} stands for the building load and Q represents the heat pump capacity. The part load factor of a heat pump, *F,* is obtained as:

$$F = \frac{Run\ Time}{1 - c_d(1 - Run\ Time)} \tag{5-61}$$

where c_d stands for an experimental factor (0.15) assuming for the transient start/stop performance penalties (ARI, 1993). This factor is called the degradation coefficient. It is read from the equation (5-61) that the greater the penalty over the degradation coefficient, the smaller the values of Run Time.

The electricity consumption of the heat pump and auxiliary pumps is calculated for all temperature bins. The heat pump electric consumption is computed as:

$$HP_{e,demand} = \frac{Capacity}{COP} \tag{5-62}$$

5.3.7.2. Supplemental heating or cooling needs

The supplemental heating or cooling needs are determined for each temperature bin simply by the difference of the building load minus the capacity of the heat pump. The electricity consumption, Q_e by the heat pump and backup pumps is obtained by:

$$Q_e = Bin(h)[\left(HP_{e,demand}F\right) + AUX_e] \tag{5-63}$$

where *Bin*(*h*) represents the hours in the bin, *F* stands for the heat pump part load factor (as explained), and AUX_e stands for the summation of all auxiliary electricity requirements.

The design of the backup heating load is obtained by subtracting the heat pump system's heating capacity at the lowest entering water temperature from the building design load. The design of the dissipater load is computed by subtracting the ground heat exchanger capacity at the highest entering water temperature from the building design cooling load.

5.4. Cost Analysis

The cost of the solar collectors and PV panels are the practical cost; quotations from actual companies were obtained. The products are well known in the market and have durability for 25 years. These are not the demonstration or low quality products that are available in regular department stores.

The future monetary value is calculated by the "future value" formula:

$$Yn = Y0\ (1 + IR)^n \tag{5-64}$$

when Yn = future \$ value in year n, $Y0$ = present \$ value, n = year, IR = inflation rate.

The actual application of this equation is in Chapter 6, case studies.

The calculation of a loan on the product has been done through a Standard Mortgage formula which is:

$$\mathrm{M} = P\ \left(\frac{[i\ (1+i)^N]}{[(1+i)^N - 1]}\right) \tag{5-65}$$

When M is the monthly payment in \$, P is the principal in \$, i = monthly interest rate, and N is the number of monthly payments.

Examples of the application of this formula are in Chapter 6.

5.5. Wind Turbine Calculation Method

The method of the sizing calculation of wind turbines is from renewable energy UK's website.

Two main concepts are considered with respect to wind turbines:

- the power output of a wind generator is proportional to the area swept by the rotor; and

- the power output of a wind generator is proportional to the cube of the wind speed.

Moving air with mass carries kinetic energy which is given by the equation:

$$E_k = 0.5 \text{ x M x } V^2 \quad (5\text{-}66)$$

where M stands for mass and is measured in kg, V represents the velocity in m/s, and E_k is the kinetic energy in joules. Air density is D, (1.23 kg/m^3 at sea level), therefore the mass of air hitting the wind turbine each second is:

$$\text{M/T (kg/s)} = \text{V (m/s) x A (m}^2\text{) x D (kg/m}^3\text{)} \quad (5\text{-}67)$$

A is area and t is the time. Other initial are already introduced. The power in the wind hitting a wind turbine with a definite swept area is given by simply inserting the *mass per second* computation into the standard kinetic energy equation (5-66), then:

$$P = 0.5 \text{ x S x D x } V^3 \quad (5\text{-}68)$$

Where P is power given in Watts, the S is the swept area in square meters, D is the air density in kg/m^3, and V is the velocity in m/s.

5.6. Summary

The method of calculation for PV arrays and wind turbines is explained. In the next chapter, sizing the PV panels is done by these calculations. Also, detailed calculations for the ground source energy system are explained with algorithm and RETScreen as follows: RETScreen is used for case studies to calculate geothermal energy systems. The mortgage and future value equations are explained for financial analysis in the next chapter.

Chapter 6: Case Studies

6.1. Introduction

In this chapter, different buildings are considered as case studies for using renewable energy. Various energy options are measured; related emission reduction is assessed. There are some incentives from the government allocated to renewable energy projects (case studies) in the financial analysis section, and are calculated based on receiving and not receiving governmental rebates. These case studies are residential houses, a commercial building, and an industrial building.

Case studies #1 and #2 are two detached houses with different energy consumption regimes which are categorized as residential buildings. Case #3 is a large public library which is characterized as a commercial building. Case #4 is a plastic injection company, which represents an industrial building.

The technologies for converting natural energy to useable energy are vacuumed solar water heaters, PV modules and ground source heat pumps. These technologies are explained in Chapters 4 and 5. Wind turbines are also described in Chapters 4 and 5, but are not practical cases for this thesis because all cases are in urban areas and according to bylaw 270-3004, wind turbines are not permitted to be installed. Besides vacuumed solar water heaters, PV modules and ground source heat pumps, some other hybrid systems, which are a combination of aforementioned renewable technologies, are designed to provide renewable energy resources for each case.

The equations used in this chapter are explained in Chapter 5. The applications of the previous chapter equation are shown in four different case studies.

6.2. Case Study #1

Case #1 is in Brampton, latitude 43.536, longitude -79.556. Case #1 is a 4+1 bedroom detached house, with five residents. In this house, furnace works with natural gas and electricity; the heating system is forced air. The living area in house is almost 214 m^2. The energy consumption in this house is under control and saving energy is respected by the household.

The electricity consumption in the last year in this household was 5,506 kWh, the average daily consumption is 15 kWh, the highest daily rate is 18 kWh and the lowest daily rate is 12 kWh. Figure 6-1 shows the electricity consumption in case #1.

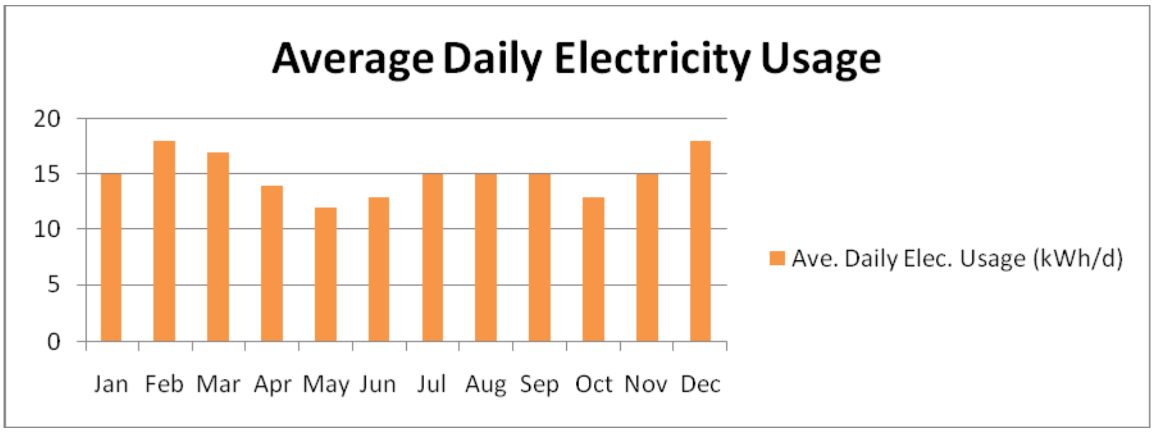


Figure 6-1, Electricity consumption for the household in case #1 (monthly bills)

The distribution of the electricity consumption in case #1 is categorized in Figure 6-2.

The natural gas consumption in this house is 2,760m^3, and the average daily natural gas consumption comes to 7.5 m^3. Figure 6-3 displays the gas consumption in case #1.

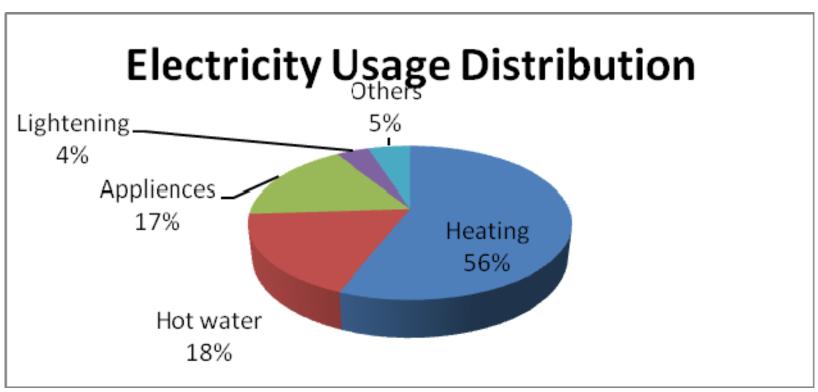


Figure 6-2, Electricity usage distribution for case #1

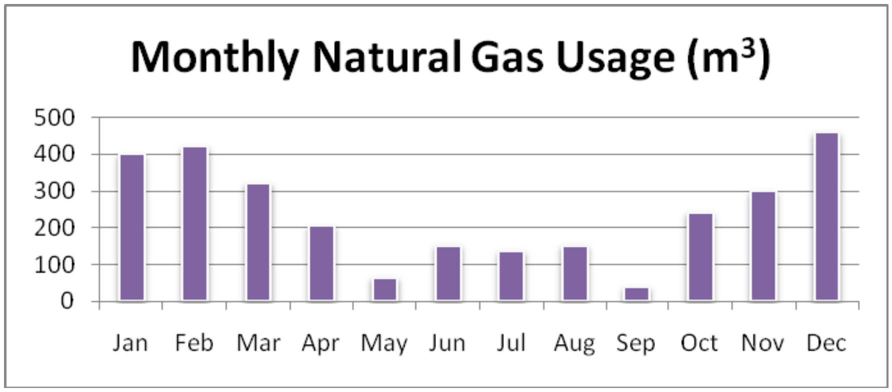


Figure 6-3, Natural Gas Consumption in case #1 (monthly bills)

6.2.1. Using Solar Water Heaters

Solar water heaters are very popular for heating domestic water. In this section, solar water heaters are customized for case #1 to heat domestic water and analysis is done from the point of energy generation, pollution reduction and cost. By using solar water heaters, the natural gas consumption is reduced. The detail of reduction is in the energy section 6.2.1.1. Figure 6-4 depicts a layout from case #1 when using solar water heaters (solar thermal) as a source of energy with other regular sources of energy, grid electricity and natural gas.

Figure 6-4, Layout of energy resources for case #1, when using solar thermal

6.2.1.1. Energy Utilization

In the energy section, the panel which produces heat is solar water panel model WSE58; this heat collector panel is chosen from WSE technology, the Canadian manufacturer. WSE58 generates 2,741.3 kJ (2600 Btu/hr).

The house in case #1 needs four solar panels, WSE58, to provide sufficient energy to heat water for household domestic hot water. The energy generated by four panels is: 2,741,310 x 4 = 11 MJ/h.

By considering seven hours of sun per day as average for all days in the year, the energy produced by these solar panels would be: 11 x 7 = 77 MJ/day

The assumption is that there are 300 days of sun per year in Canada. Hence, the energy produced by solar collectors is 23.1 GJ per year.

Furthermore, according to the Natural Gas Fact website, 1 m^3 releases 37234 kJ (35,314.6 Btu) energy.

This energy is released from 620.4 m^3 of natural gas (23.1/37,233,949=620.4), in other words, gas consumption is reduced by 620.4 m^3 every year. In a life period of 25 years for the solar panels, this saving is 15,510 m^3 of natural gas.

6.2.1.2 Emission Reduction

According to the Wikipedia website, natural gas as a source of energy creates 53 kg CO_2 in the atmosphere when it releases 1,054,350 kJ energy (117 lbs CO_2= 1 million Btu).

In case #1, by releasing 23.1 MJ energy from the natural gas, 1161 kg of CO2 will be emitted into the atmosphere. This is 290,525 kg CO_2 in 25 years of the panels' life. Figure 6-5 displays CO_2 emission reduction in 25 years of the panels' life.

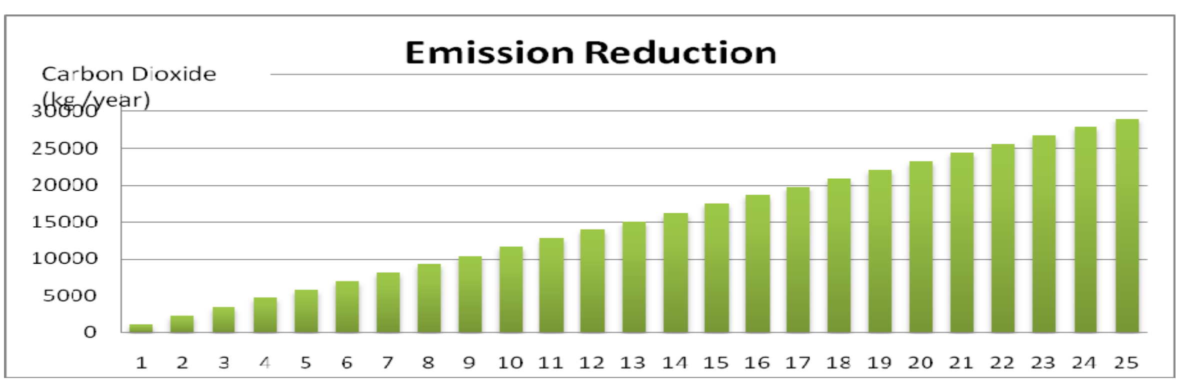


Figure 6-5, CO_2 reduction by solar heater panels for case #1

6.2.1.3. Cost

In order to calculate the cost of the project, it is necessary to know the price of the solar water heater. The cost of each solar heater panel (WSE58) is $1,078.00.

The first incentive is a13% government rebate for renewable energy projects. The calculations are as follows:

The cost of these four solar water heater panels is $4,951.55. The government incentive is approximately $643.70. The cost of 620.4 m^3 , based on today's price, is $188.60, the saving in the natural gas bill payment per year. The value of this saving is calculated by equation (5-64) when Y0=188.6, IR=3%. The life of the equipment is 25 years, therefore n=1 to 25, however, it is calculated through:

$$Yn = Y0\ (1 + IR)^n$$

$$Yn = 188.6\ (1 + 0.03)^n$$

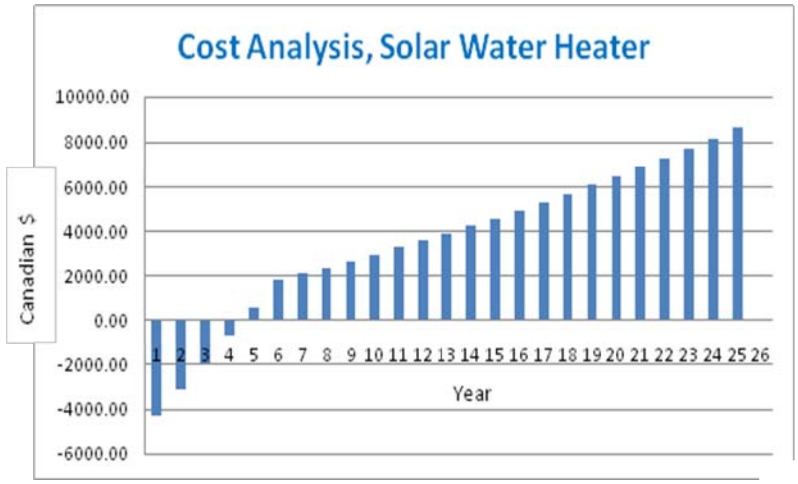
The standard mortgage equation (5-65) gives the monthly payment of the loan on the initial cost, when P= 4951.55 – 643.7 = 4307.85, i = 4.5%/12 = 0.0045, and payment is in five years.

$$M = P\ \left(\frac{[i\ (1+i)^N]}{[(1+i)^N - 1]}\right)$$

$$M = 4307.85 \left(\frac{[0.004\ (1 + 0.004)^{120}]}{[(1 + 0.004)^{120} - 1]}\right)$$

Using the standard mortgage formula, monthly payments come to $82.09, and the loan payment per year is $985.03.

These numbers are displayed in a diagram. Figure 6-6 shows both financial equations by two slopes in the diagram. The first slope is more aggressive; it is the combination of the future equation and mortgage equation. After paying off the mortgage in less than five years, savings will start. The remaining 20 years of the panels' life is accumulating in the savings.



Year

Figure 6-6, Cost summary for solar heater panels with governmental rebate for case #1

In the second set of calculations, no incentive is measured and calculations are slightly different.

The cost of these four solar water heater panels is \$4,951.55. As mentioned, the cost of 620.4 $\mathbf{m^3}$ is \$188.60 per year. The value of this saving is calculated by the future equation (5-64) when Y0=188.6, IR=3%. The life of the equipment is 25 years, therefore n=1 to 25, however, the calculation is

$$Yn = Y0\ (1 + IR)^{n}$$

$$Yn = 188.6\ (1.03)^{n}$$

The standard mortgage equation (5-65) gives the monthly payment of the loan on the initial cost, when P= 4,951.55, i = 4.5%/12 = 0.0045, and payment is in five years.

$$M = P\left(\frac{[i\ (1+i)^{N}]}{[(1+i)^{N} - 1]}\right)$$

$$M = 4951.55\left(\frac{[0.004\ (1 + 0.004)^{120}]}{[(1 + 0.004)^{120} - 1]}\right)$$

Using the standard mortgage formula, monthly payments come to \$94.35, and the loan payment per year is \$1,132.22.

Figure 6-7 illustrates both financial equations by two slopes in one diagram. The first slope is more aggressive; it is the combination of the future equation and mortgage equation. After paying off the mortgage in less than five years, savings will start.

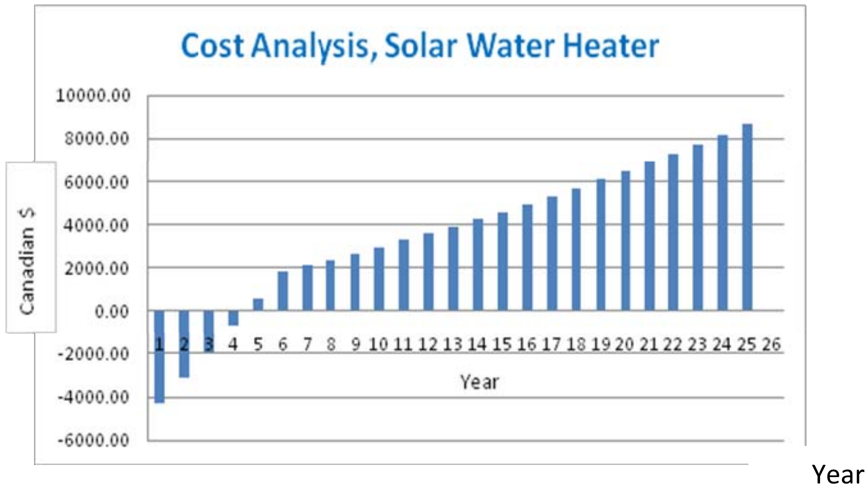


Figure 6-7, Cost summary of solar heater panels without governmental rebate for case #1

6.2.2. Using Photovoltaic Panels

As mentioned. PV panels are good technology to generate electricity for the household. Sizing the PV panels is done by the method explained in Chapter4. In this section, PV panels are sized for case #1, thereby reducing the request for electricity. Section 6.2.2.1 shows the details of calculation and the amount of electricity which PV panels generate. Figure 6-8 depicts the energy layout for case #1 when PV panels (solar electricity) are a source of renewable energy besides conventional energy sources, grid electricity and natural gas.

Figure 6-8, Layout of energy resources for case #1 when using solar electricity

6.2.2.1. Energy Utilization

The PV panel is chosen from SCM series 210, which is the most popular PV panel in Scandinavia, and comes in larger panel wattage. The panels used in the calculations are 210 W and 215W.

The sun hour or insulation coefficient for Pearson International Airport is a minimum of 1.08 kWh/m^2/d to a maximum of 5.98 kWh/m^2/d (based on the NASA data) the average coefficient on insulation is 3.53 kWh/m^2/d.

As the average electricity consumption in case #1 is 15 kW, and the average insulation coefficient is 3.53 kWh/m^2/d in the Toronto area, electricity consumption by the sun hours per day would be 15 / 3.53 = 4.25 kW = 4250 W (AC).

According to the manufacturer (REC Group), information CEC for the inverter is 194; information CEC for the solar modules series SCM 210 is 0.94.

4250 / (CEC=194) = 22 W, and 22 / (CEC=0.94)=24 , 24 is the number of panels . For having better array configuration, 215 W is replaced for 210 W panel and 22 panels is chosen. Configuration is two rows of strings with 11 panels of module 215W in each string.

(Inverter: Xantrax GT 2.8 208/240 V grid tie, CEC 94%)

The angles of the PV modules in 4 seasons are as follows (As mentioned in Figure 4-10):

Fall/Spring: Angle= Latitude = 43.5°

Summer: Angle=Latitude – 15 = 43.5 -15 = 28.5°

Winter: Angle=Latitude + 15 = 43.5 +15 = 58.5°

With the change of seasons, it is strong recommended that the PV modules be changed as well. This ensures harnessing maximum energy from the sun.

6.2.2.2. Emission Reduction

Electricity generates in different plants with different fuels. In Canada, resources are hydro, thermal, nuclear, combustion engines, and very limited renewable energy. Depending on fuel resources, pollution due to electricity generation varies. In the report entitled "Power Generation in Canada", published on the Canadian Electricity Association's website, Ontario's electricity generation configuration in 2004 was:

37 TWh from hydro;

45 TWh from thermal (mainly coal-based power plants);

63 TWh nuclear; and

6.7 TWh combustion engines.

As previously mentioned, PV panels create roughly 22 x 215 x 90% x 3.53 = 15 kW of electricity per day.

According to the calculator in Plug into Green Canada's website, generating an average of 450 kWh/month, 1580 kg of CO_2/year are emitted into the atmosphere in Ontario. In other words, the designed PV system saves 1580 kg CO_2/ year or 39,500 kg CO_2 in the project's 25 year lifespan; this is depicted in diagram 6-9.

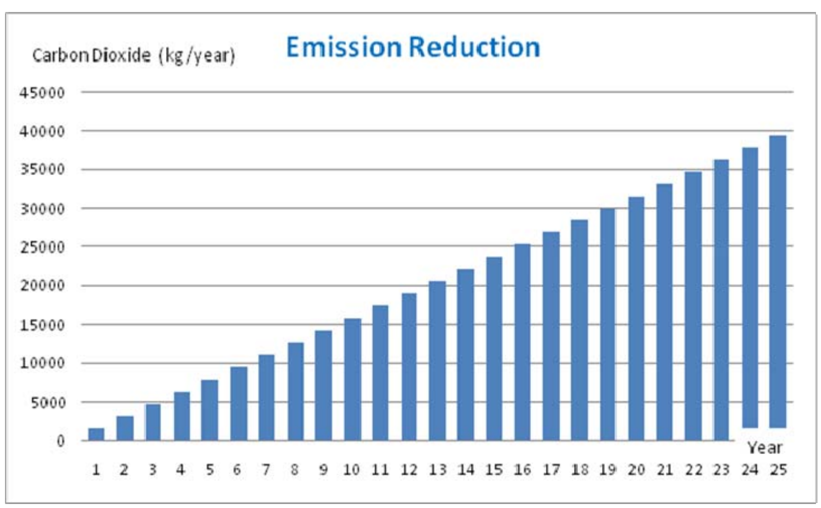


Figure 6-9, CO_2 reduction by PV panels for case #1

6.2.2.3. Cost Analysis

The cost of each PV panel of 210W from the SCM series is $1,541.65, from the same set, the cost of module 215W is $1,578.62. The cost for 22 panels is $34,729.64, plus 13% tax, for a total cost of $39,244.50. If the government considers a 13% rebate, the total cost is then $34,142.72.

To calculate the loan payment, when the principal is $34,142.72, and the payment is in 10 years, N = 12 X 10 = 120, and i = 4.5%, by using the standard mortgage equation (equation 5-65), the monthly payment comes to $368.85 and the annual payment amounts to $4,426.18.

Generating an average of 450 kWh/month means a saving of $55.60 per month or $667.20 per year based on the present cost of electricity. The life of the PV system is 25 years. The value of savings in 25 years can be calculated by the future value equation (equation 5-64), when n = 25 years, IR = 3% and Y0 = $667.2.

Figure 6-10 illustrates financial balance. This diagram presets two slopes which represent two equations. This chart also displays that after seven years, the initial cost will be paid off by accumulated savings.

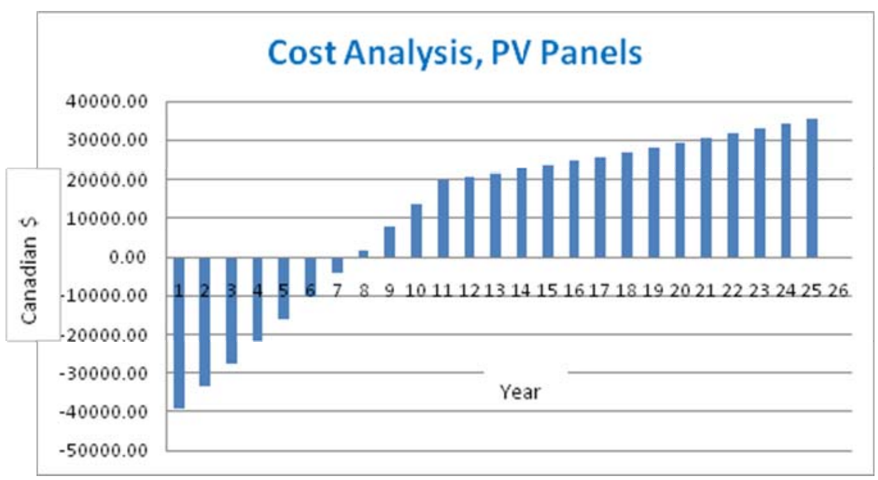


Figure 6-10, Cost summary of PV solar panels with governmental rebate for case #1

The second option has no government incentive in the assumption. The cost of the project is then $39,244.50. The loan principal is $39,244.50, the monthly payment is $423.97, and the annual payment of the loan is $5,087.57. The annual savings on the electricity bill is the same as last option, $667.20.

Figure 6-11 depicts financial balance. This chart displays that after seven years, the initial cost will be paid off by accumulating the saving as per previous years. Afterwards, it is simply an overall saving on the electricity bill, for the remainder of the project's life.

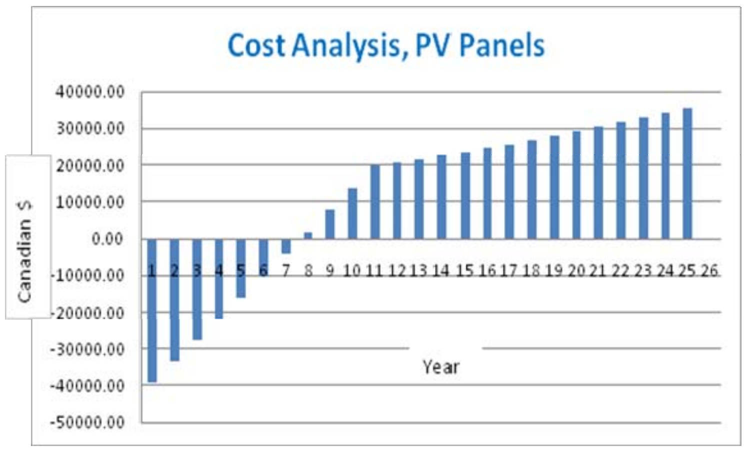


Figure 6-11, Cost summary of PV solar panels without governmental rebate for case #1

6.2.3. Using Geothermal System

The ground source energy system as explained in Chapter 4 is an amazing source of renewable energy because it is "reliable", that is, always available without interruption from mother nature. Moreover, the ground source heat pump's cost effectively provides energy for heating and cooling the building. The average coefficient of performance (COP) of a ground source energy system is 4, which means a geothermal system provides 4 units of energy (heating or cooling) by getting 1 energy unit (electricity). Particularly in Canada, with such harsh and long winters, using ground source systems is a very intelligent decision. Further explanation about the cost effectiveness of geothermal systems is provided in section 6.2.3.3.

Figure 6-12 depicts the layout of case #1 when using geothermal energy as a renewable source of energy together with a conventional source of energy, grid electricity and natural gas. By using geothermal energy, electricity consumption for heating and cooling is reduced to one/fourth. Section 6.3.2.1 shows the energy calculation in greater detail.

Figure 6-12, Layout of energy resources for case #1, when using geothermal energy

6.2.3.1. Energy Utilization

For sizing the geothermal system in case #1, RETScreen is utilized. The detail of modeling has been explained in Chapter 5. In section 5.4, different approaches such as the descriptive data method or energy method, for modeling a geothermal project are described. There are many constants involved in the equations like specific heats, density, and thermal conductivity. RETScreen uses its data to replace these constants. Ultimately, RETScreen calculates all losses (conductive and convective), including all gains (solar gains and internal gains), and fresh air load; then adds up the heat load for heating or cooling the space and produces the power of the geothermal system which can generate the heat load. For case#1, all data is entered into RETScreen. RETScreen processes data by using equations (5-1 to 5-64) to size the ground source heat pump for case #1.

The results are shown in Figures 6-13 and 6-14.

The practical meaning is that to run the heating and cooling system in case #1, a heat pump with capacity 51633 kJ/hr is needed, while the heat loss for case # 1 is 44282 kJ/hr. This is matched with model GT049 from Geosmart Energy. GT049 has COP 4.1 for heating mode and COP 5.4 for cooling mode. This unit is replaced in the utility room with a furnace which runs on natural gas. The pipe loop for case #1 is a closed loop with cycling ethanol, R-410A refrigerant. Pipes are 3.1 cm in diameter and 440 m long. These 220 m pipes are placed into two holes with a length of 110 m each. The holes' diameter is 12.5 cm. In the backyard, close to the utility room, these two holes are bored through the earth with special machines. In each 110 m hole there is a U-shaped pipe with a total length of 220 m; for the two holes, a 440 m pipe is available for circulation of R-410A refrigerant. Through this path of 440m, R-410A refrigerant exchanges heat with soil; either damps the heat into the ground or extracts the heat from the soil. Table 6-1 shows a summary of the ground source energy system for case #1.

Table 6-1, Ground source energy system for case #1

Geothermal System Spec.	
System Capacity	51633 kJ/hr
Number of pipes	2 U shape
Length of pipes	440 m
Circulating Liquid	R-410A refrigerant
Cooling COP	5.1
Heating COP	4.1
Cooling Capacity	15 kW
Heating Capacity	11kW

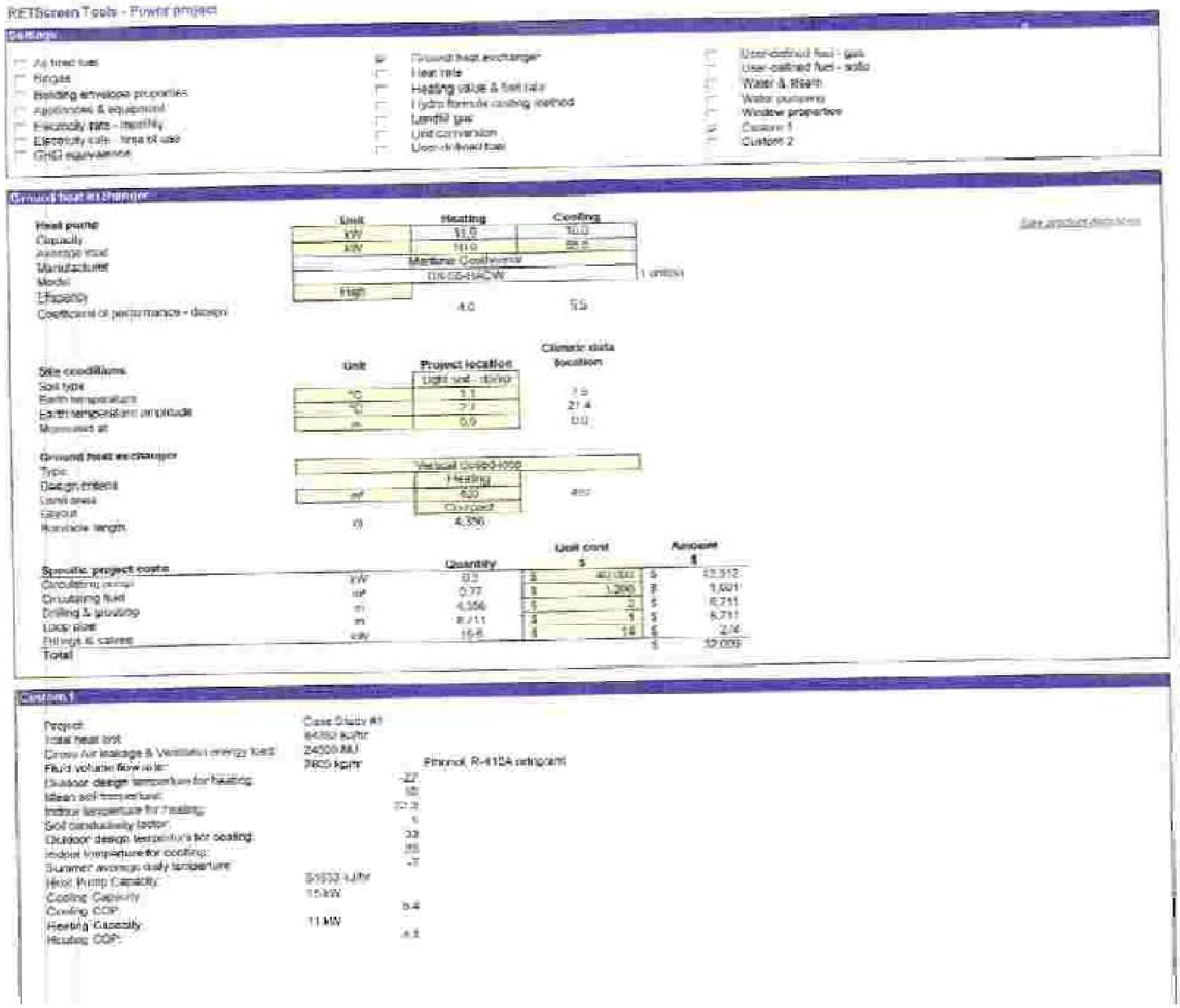


Figure 6-13, RETScreen results for Case #1

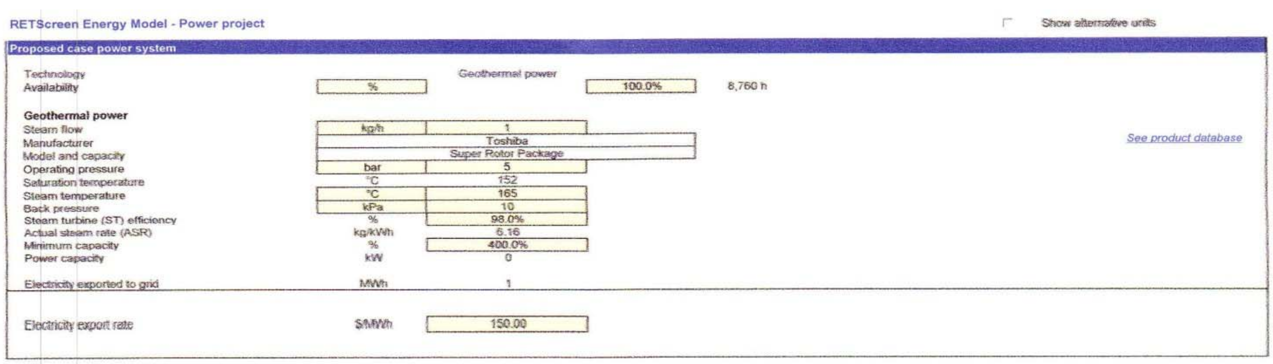


Figure 6-14, RETScreen results for case #1

6.2.3.2. Emission Reduction

Before installing the ground source heat pump, the furnace is taken out. This means that one main user of natural gas is eliminated from the system. Therefore, the consumption of the gas is drastically reduced. According to diagram 2-3 in Chapter 2, 61% of household energy is used for heating and cooling the space. Natural gas consumption in case #1 is 2,760 m^3 per year natural gas usage is now reduced by 1683 m^3.

1683 m^3 natural gas = 62,665 MJ energy (1683 x 37.234 = 62665, Natural gas fact website)

62665 / 1054.4 = 59.4

59.4 x 53 = 3149.9 kg CO_2 (53 kg CO_2 = 1054.4 MJ, Wikipidia)

Hence, by not burning 1683 m^3 of natural gas per year, 3149.9 kg of CO_2 per year will not be released into the atmosphere. The environment is protected from 62,998 kg of CO_2 during the 20 year life cycle of the geothermal system. Figure 6-19 illustrates the environmental protection by the ground source heat pump in 20 years.

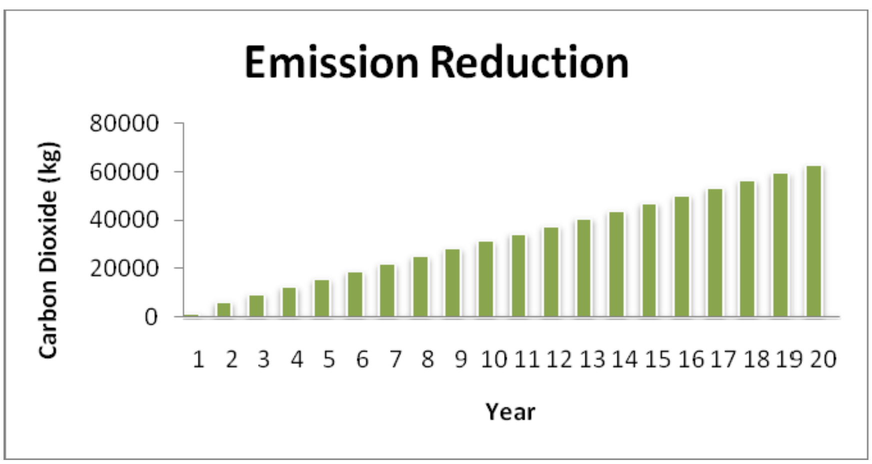


Figure 6-19, Emission reduction by using the geothermal system for case #1

6.2.3.3. Cost Analysis

The cost of the ground source heat pump GT049 is $12,000, and the cost of drilling holes, trenching, duct work, pump, thermostat, and ethanol is $20,000. There is an additional 13% tax of $4,160. The total initial cost of having the geothermal system running in case #1 is $36,160. The government rebate for this deal is $9,879; therefore, the final cost is $26,281.

By using equation (5-65) and an assumption of 10 years amortization of the mortgage, the annual payment for a $26,160 loan is $3,407, when interest rate is 4.5%.

Additionally, by having the geothermal system in place as mentioned in the last section, 1683 m^3 of natural gas will be saved. This translates into a saving on natural gas of $511.60 per year. By using equation (5-64), the saving over a 20 year period is calculated.

There is a governmental rebate of $9,879, and there are savings on natural gas bills for every year as calculated with the future value equation, equation (5-64). Figure 6-16 shows the financial balance. This chart displays that after seven years, the initial cost is paid off by accumulating the savings from previous years. Afterwards, it is simply savings on the natural gas bills, for the remainder of the project's life.

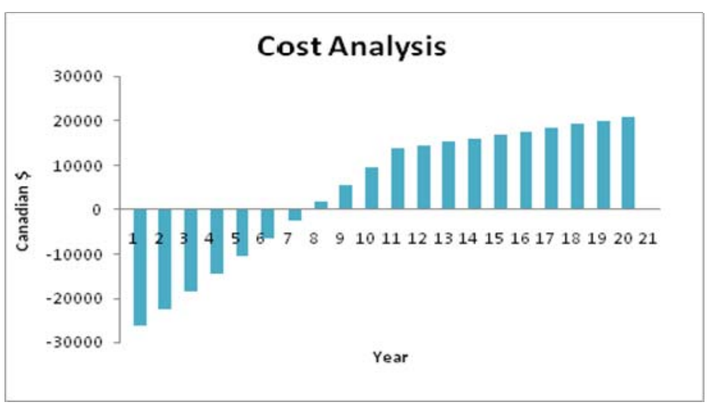


Figure 6-16, Cost analysis for the geothermal system, with a Governmental rebate, for case #1

Usually governmental incentives are for a certain period of time, and then the assumption for cost analysis would be payment of all initial costs without any rebate. In this case, the total cost is $36,160. Therefore, the principal of the loan is $36,160. The amortization for the loan is ten years with an interest rate of 4.5%. The annual payment is $4,687 for this loan, equation (5.65). The amount of saving on the natural gas bills remains the same at $511.60.

The summary of all financial transactions during 20 years of the geothermal system's life is illustrated in Figure 6-17. This chart also displays that after seven years, the initial cost is paid off by accumulating saving in previous years. Going forward, it is simply savings on natural gas bills for the remainder of the project's life.

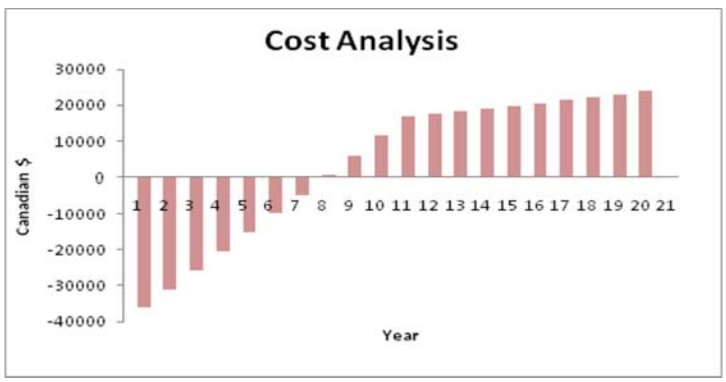


Figure 6-17, Cost analysis of the geothermal system without a governmental rebate for case #1

6.2.4. Hybrid System #1

As previously cited, geothermal is a reliable source of energy which provides heating and cooling energy. The ground source heat pump obtains four units of energy from the ground by spending one unit of energy (electricity), thereby providing exactly five units of energy for cooling or heating purposes. This means that the geothermal system is an ideal candidate for alternative energy from the point of reliability and efficiency. As well, this superior technology needs only one-fifth of its energy to run the entire system.

The electricity needed by the ground source heat pump is supplied by another source of renewable energy. The entire heating and cooling system therefore would run with natural energy. This source of energy could be photovoltaic panels, which convert solar energy to electricity and can easily be built up to meet the electricity demand level.

Figure 6-18 shows the layout of hybrid system #1 for case #1. In this design, geothermal energy and PV panels (Solar Electricity) are the source of renewable energy, and grid electricity plus natural gas are the conventional sources of energy for case #1.

Figure 6-18, Layout of energy resources for case #1, when using hybrid system #1

Subsequently, the suggested hybrid system for case #1, which is an urban area, is coupling PV panels and geothermal system. This suggested system remains the same for rural areas by adding a number of batteries as electricity storage to the geothermal system and PV panels. Also, coupling the ground source heat pump and wind turbines with a set of batteries is another alternative hybrid system for a country area.

6.2.4.1. Energy Utilization

For the ground source heat pump GT049, the cooling capacity is 15 kW and the heating capacity is 11 kW. The highest capacity of this machine is therefore 15 kW, as previously mentioned; one-fifth of this energy supplies to the heat pump. Therefore, 15/5 = 3 kW of energy, in the form of electricity, is needed to run the pump. Subsequently, PV panels should provide 3kW/day.

The sun hours or insulation coefficient for Pearson International Airport is a minimum of 1.08 kWh/m^2/d to a maximum of 5.98 kWh/m^2/d (based on NASA data); the average coefficient on insulation is 3.53 kWh/m^2/d.

As the average electricity consumption for the hybrid design of case #1 is 5 kW, the average insulation coefficient is 3.53 kWh/m^2/d in Toronto area. Hence, electricity consumption by the sun hours per day is:

5 / 3.53 = 1.4 kW = 1400 W (AC)

According to the manufacturer, REC Group, information CEC for the inverter is 194 and for the solar modules series SCM 210 is 0.94.

1400 / (CEC=194) = 7.2 W, and 7.2 / (CEC=0.94) =7.7

7.7 $\cong$ 8 is the number of panels. Then, 8 panels of 210w deliver the needed electricity for the ground source heat pump.

By coupling the ground source heat pump GT049 from Geosmart Energy with a set of eight photovoltaic panels, 210w from REC Group series 210, the cooling and heating in case #1 will be totally with natural energy.

6.2.4.2. Emission Reduction

Since the system is hybrid, emission reduction is combined from two categories: one category is eliminating burning the natural gas and the other category is reducing electricity consumption. The first part, which is from reducing the natural gas consumption, is already calculated in section 6.2.3.2. It is estimated to eliminate 1683 m^3 of natural gas per year which corresponds with eliminating 3149.9 kg CO_2 per year.

The second part of emission reduction is through cutbacks in electricity. According to the calculator in the Plug into Green Canada website, to generate an average of 3 x 30 = 90 kWh of electricity per month, 316 kg CO_2per year is emitted into the atmosphere in Ontario. In other words, the designed PV system saves 316 kg CO_2/year.

The hybrid system, as a combination of the ground source heat pump and photovoltaic panels, together protects the environment by eliminating:

3150 + 316 = 3466 kg CO_2/year

This is 69,320 kg CO_2 per 20 years of the hybrid system's life. Figure 6-19 illustrates the environmental protection year by year during 20 years.

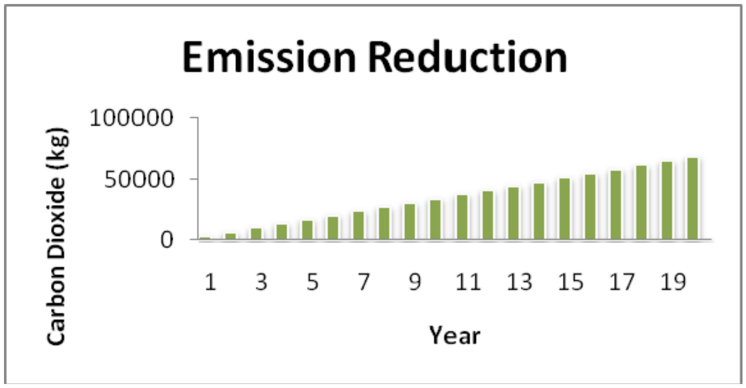


Figure 6-19, CO_2 reduction by geothermal system for case #1

6.2.4.3. Cost Analysis

In view of the fact that the system is a hybrid and combined from two technologies, the geothermal system and photovoltaic panels, the cost is combined from the cost of both technologies. The cost of the ground source heat pump is already calculated at $36,160 in section 6.2.2.3. The cost of a set of eight PV panels of 210w from the REC Group is:

8 x $1541.65 = $12,333.20

Therefore, the total cost for the hybrid system is:

$36,160 + $12,333.20 = $48,493.20

This is the cost of the hybrid system which runs the heating and cooling system, free of conventional energy, solely by using renewable energy. At this time, there is an incentive of $11,499.30 from the government for this project; therefore, the cost after the rebate is $36993.90.

By using the mortgage equation, equation (5-65), the annual payment for the $36,993.90 loan is $4,795.81, when the interest rate is 4.5% and amortization is ten years.

On the other hand, there are some savings on energy bills by using the hybrid system. Saving on natural gas by using the ground resource heat pump is already obtained at the amount of \$511.60 in section 6.2.2.3. The saving on electricity bills because of using PV modules is \$11.10 in total. The saving on energy bills is:

\$511.60 + \$11.10 = \$522.70

By replacing \$522.70, the total saving using the future value equation (5-64), the value of saving on each year is calculated.

These numbers are depicted in a chart to show the trend of the financial situation of the hybrid #1 project for case #1. Figure 6-20 depicts the financial balance in each year of the project's life as follows:

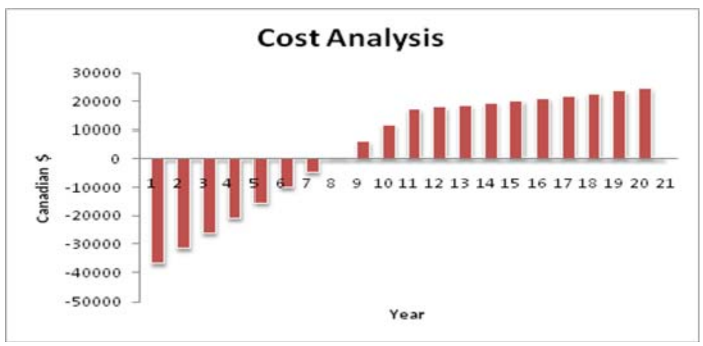


Figure 6-20, Cost analysis of hybrid #1 with the governmental rebate for case #1

This diagram depicts two slopes which represents the two equations. This chart also displays that after eight years, the initial cost will be paid off by accumulating savings from previous years. Afterward, it is simply savings on natural gas bills and electricity bills, for the remainder of the project's life.

The government incentive may be eliminated; therefore the financial analysis will be done another time with the assumption that there is no reimbursement. In this case, the principal of the loan is equal to the total cost of the project which is \$48,493.20. With the same amortization of ten years and an interest rate of 4.5% using the mortgage equation, equation (5-65), the annual payment of the loan is \$6,286.55. Saving on energy bills remains the same at \$522.70. The savings accumulate year after year through the future value equation, equation (5.64). The financial balance resulting from the loan payment and savings of the energy bills is calculated within 20 years of the project's life. Figure 6-21 depicts the balance of the financial situation in each year of running the hybrid project for case #1. This chart also displays that after eight years, the initial cost is paid off by accumulating the savings from previous years. Afterwards, it is simply savings on natural gas bills and electricity bills for the remainder of the project's life.

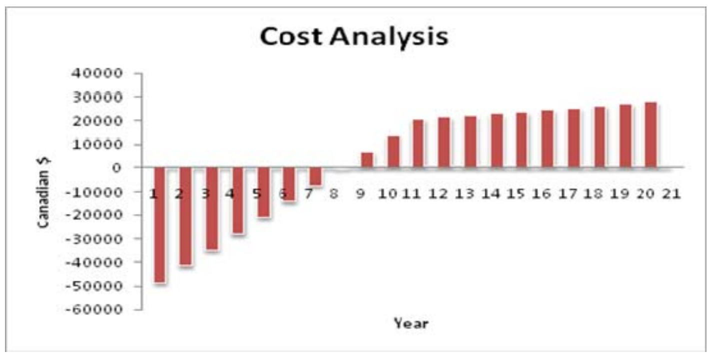


Figure 6-21, Cost analysis of hybrid system#1 without the governmental rebate for case #1

6.2.5. Hybrid System #2

The second hybrid system is defined through solar technologies by combining PV panels for generating electricity and solar water heaters for heating the water. In hybrid system #2, electricity and natural gas consumption are reduced. The reduction is calculated in the following paragraphs. This hybrid system is directly dependent on solar energy. In hybrid system #2, grid electricity and natural gas are in the system as a backup system for the time when there is not quite enough sun. However, for long sunny days, extra energy would overflow to the grid. Figure 6-22 depicts the layout of energy sources in case #1.

Figure 6-22, Layout of energy resources for case #1, when using hybrid system #2

6.2.5.1. Energy Utilization

Hybrid system #2 consists of solar water heaters (solar thermal) and PV panels (solar electricity). Solar water heaters are calculated in section 6.2.1.1, and PV modules are computed in section 6.2.2.1. Based on this previous assessment, hybrid system #2 includes four panels of WSE58 as solar thermal energy for converting solar energy to 11MJ/hr, plus 22 panels of PV modules 215W to generate 15 kW/day. The configuration of PV modules and the angle of panels are described in section 6.2.2.1.

6.2.5.2. Emission Reduction

With the same logic, emission reduction for hybrid system #2 is equal to emission reduction by four panels of WSE58, calculated in section 6.2.1.2 along with emission reduction by 22 PV modules computed in section 6.2.2.2. Then, the quantity of emission reduction by hybrid system #2 is:

1,161 + 1,580 = 2,741 kg CO_2 /year

2,741 X 25 = 68,525 kg CO_2 per 25 year project life time

Figure 6-27 shows the emission reduction by hybrid system #2 in 25 year period.

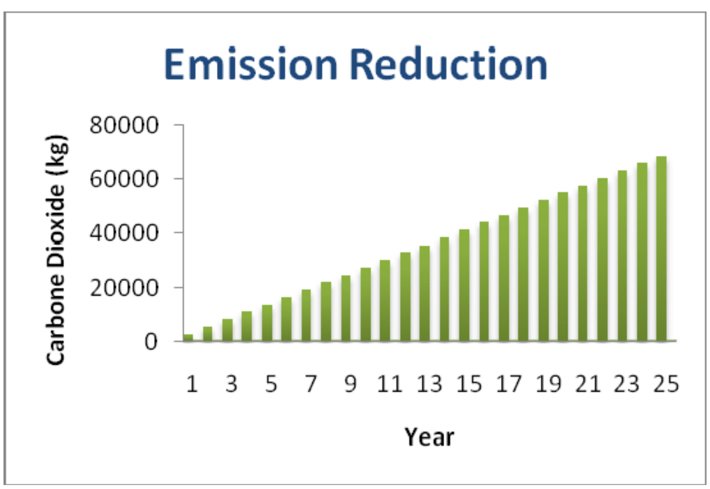


Figure 6-27, CO_2 reduction by hybrid system #2 for case #1

6.2.5.3. Cost Analysis

The cost of the hybrid system #2 is the addition of four solar water tubes and 22 PV modules; these costs are calculated in section 6.2.1.3 and 6.2.2.3, respectively. Then, the cost for the hybrid system #2 is:

\$4,951.55 + \$39,244.50 = \$44,196.10

The government incentive for this project is 13% at the present time, bringing the dollar value of the rebate to \$5,745.50.

Savings over the gas and electricity bills are as follows (details of these savings are described in sections 6.2.2.3 and 6.3.2.1):

\$188.60 + \$55.60 = \$244.20 per month

\$244.20 X 12 = \$2,930.40 per year

The dollar value of this saving increases according to equation (5-64).

The first assumption is computing the financial balance by considering the governmental incentive. Then the principal is:

\$44,196.10 - \$5,745.50 = \$38,450.60

The standard mortgage equation, equation (5-65), gives the monthly payment of the loan on the initial cost, when P = \$38,450.60, and payment is in 10 years. i = 4.5%/12 = 0.0045. By replacing the numbers in the standard mortgage equation, the monthly payments come to \$415.39, and the loan payment per year is \$4,984.65. Figure 6-24 illustrates the financial balance, and also shows that after six years, the mortgage is paid off.

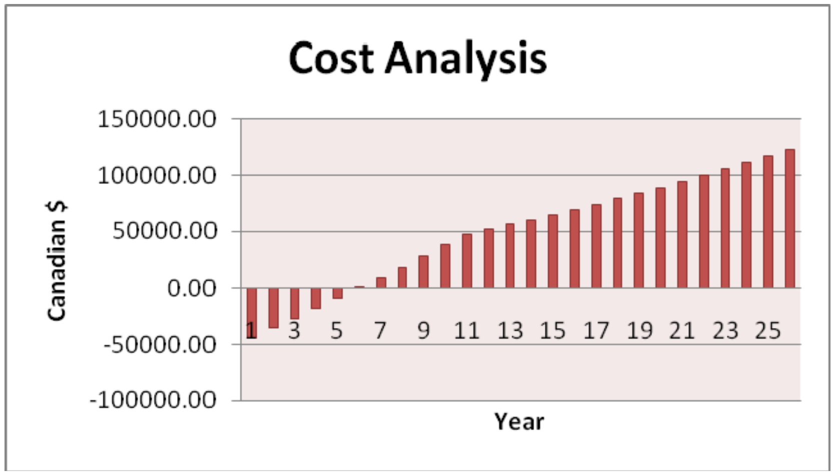


Figure 6-24, The summary of the financial balance for hybrid system #2 with the government rebate for case #1

The second assumption is when there is no government rebate for purchasing renewable energy equipment. In this circumstance, the principal is the same as the product cost, which is \$44,196.10. Using the standard mortgage equation, equation (5-65), the monthly payment of the loan is \$477.46 and payment for a year is \$5,729.48 for 10 years. The saving on the energy bills stays the same. All financial calculations for each year are summarized in Figure 6-25.

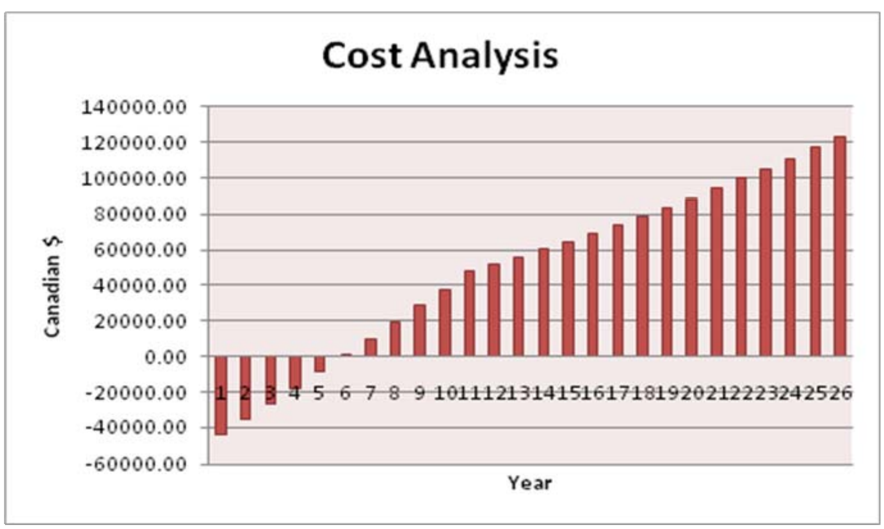


Figure 6-25, The summary of financial balance for hybrid system #2 without the governmental rebate for case #1

6.2.6. Hybrid System #3

The third combination of the hybrid system for case #1 with available technologies is geothermal system and solar thermal energy. Ground source energy is a superior technology for heating and cooling with one-fifth of the energy. Solar water heaters are designed for case #1 to provide domestic hot water for household use. In this system, energy consumption is drastically reduced because the main portion of energy consumption, based on Figure 6-2, is used for heating/cooling (57%) and hot water (17%). A total of 74% energy usage is targeted to be reduced significantly in case #1. Grid electricity and natural gas are still sources of energy in case #1, however, the amount of usage is hugely reduced. Figure 6-26 illustrates the layout of energy resources in case #1 when hybrid system #3 is in the picture as the technology for providing natural energy.

Figure 6-26, Layout of energy resources for case #1, when using hybrid system #3

6.2.6.1. Energy Utilization

Hybrid system #3 consists of solar water heaters (solar thermal) and the ground source heat pump (geothermal system). Solar water heaters are calculated in section 6.2.1.1, and geothermal system is computed in section 6.2.3.1. Based on previous assessments, hybrid system #2 includes four panels of WSE58 as solar thermal energy for converting solar energy to 11MJ/hr as well, a GT049 generates 15 kW/day cooling energy or 11 kW/day heating energy.

6.2.6.2. Emission Reduction

Following the same logic, emission reduction for hybrid system #3 is equal to emission reduction by four panels of WSE58 (section 6.2.1.2) plus emission reduction by the ground source heat pump GT049 (section 6.2.3.2). Hence, the quantity of emission reduction by hybrid system #3 is:

1,161 + 3,149.9 = 4,310.9 kg CO_2 /year

4,310.9 X 20 = 86,218 kg CO_2 per 20 year project life time

Figure 6-27 shows the emission reduction by hybrid system #3 in 20 years of working life.

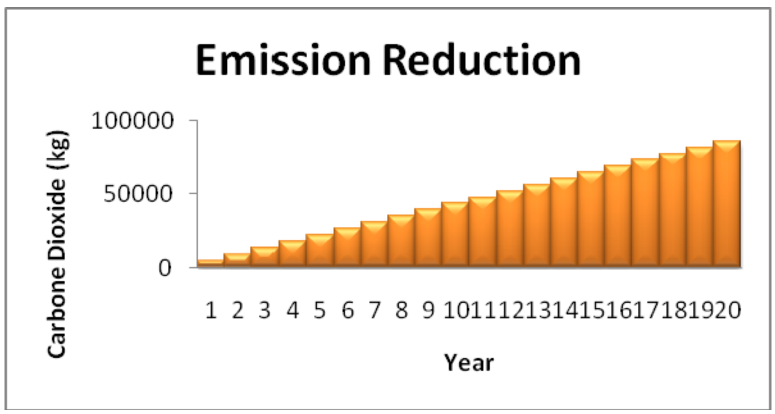


Figure 6-27, CO_2 reduction by hybrid system #3 for case #1

6.2.6.3. Cost Analysis

The cost of the hybrid system #3 is the addition of four solar water tubes; these costs are calculated in section 6.2.1.3 and 6.2.3.3, respectively. The cost for the hybrid system #3 is:

$4,951.55 + $36,160 = $41,111.60

The government incentive for this project is 13% at the present time, with the dollar value of the rebate being $10,522.70.

Savings over gas and electricity bills are (details of these savings are described in sections 6.2.2.3 and 6.3.2.1):

$188.60 + $43 = $213.60 per month

$213.60 X 12 = $2,779.20 per year

The dollar value of this saving increases according to the future value equation, equation (5-64).

The first assumption is computing the financial balance by considering the government incentive. Then the principal is:

$41,111.60- $10,522.70= $30,589

The standard mortgage equation, equation (5-65), gives the monthly payment of the loan on initial cost, when P = 30,589, i = 4.5%/12 = 0.0045, and payment is in 10 years. By replacing the numbers in the standard mortgage equation, monthly payments come to $330.46, and the loan payment per year is $3,965.48. The summary of each year's balance is illustrated in Figure 6-28 as follows:

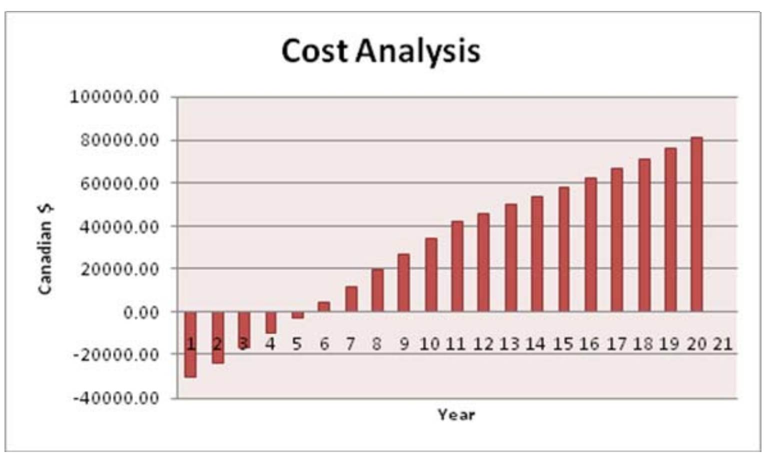


Figure 6-28, The summary of the financial balance for hybrid system #3 with the government rebate for case #1

The second scenario assumes no government rebate for purchasing renewable energy equipment. In this circumstance, the principal is the same as the product cost which is $41,111.60. Using the standard mortgage equation, equation (5-65), the monthly payment of the loan is $444.10 and payment per year is $5329.60 for 10 years. The savings on the energy bills stays the same. All financial calculations for each year are summarized in Figure 6-29.

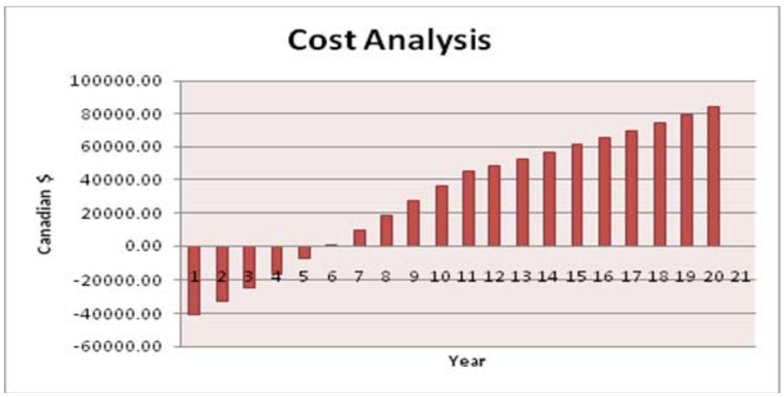


Figure 6-29, The summary of the financial balance for hybrid system #3 without the government rebate for case #1

6.3. Case Study #2

Case #2 is another detached house in Oshawa, latitude 43.696 and longitude -78.871. The specification of this house is almost the same as case #1, 4 bedrooms with five residents. In this house the furnace runs on natural gas, and the electricity and heating system are forced air as well. The living areas in these houses are approximately 215 m^2 . The first floor consists of the kitchen, the living/dining room, the family room, and a bathroom; the second floor is made up of four bedrooms, and two bathrooms, and the basement is a full basement.

The main difference between case #1 and case #2 is the energy consumption pattern. Energy usage in case #2 is significantly higher than in case #1. Natural gas and electricity consumption are both noticeably higher than in case #1.

The electricity consumption in the last year in this household was 13303 kWh, the average daily consumption is 36.4 kWh, and the highest daily rate is 44 kWh. Figure 6-30 displays the average daily electricity consumption in the last year for case #2.

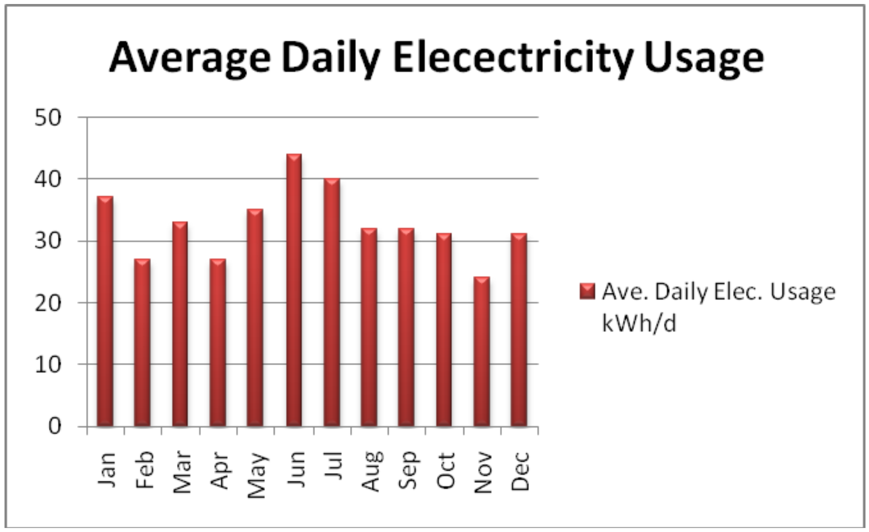


Figure 6-30, Average daily electricity consumption in case #2 (monthly bills)

The distribution of energy consumption in case #2, as a regular household, is almost the same as in case #1. Figure 6-6 shows the electricity distribution in case #2.

The natural gas consumption is 3,980 m^3; therefore, the average daily natural gas consumption for the case #2 household is 10.9 m^3. Figure 6-31 depicts the average natural gas consumption for the household in case #2.

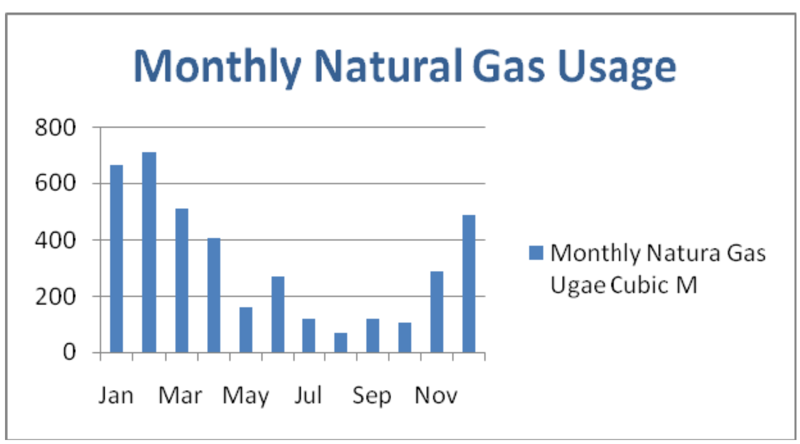


Figure 6-31, Natural gas consumption in household case #2 (energy bills)

6.3.1. Using Solar Water Heaters

Solar water heaters are used for heating domestic water. In this section, solar water heaters are customized for case #2 and an analysis is done from the point of energy generation, pollution reduction and cost. As the number of people in the household in both cases is the same, the number of solar collector panels in both cases is the same as well. Thus the calculation for energy, emissions and cost is the same, too. Figure 6-5, Figure 6-6, and Figure 6-7 display these results for case #2.

Figure 6-32 shows the layout of energy resources for case #2. Solar thermal is the renewable source of energy besides two other conventional sources of energy - grid electricity and natural gas. Solar thermal energy reduces natural gas consumption to 620 m^3/year, as it has been calculated in section 6.2.1.1.

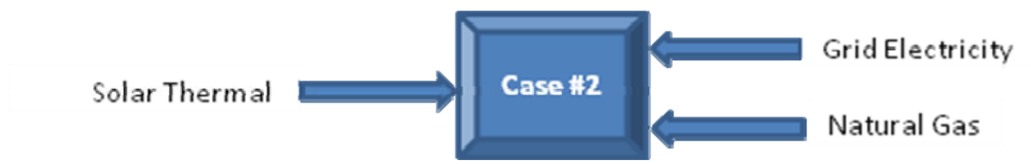


Figure 6-32, Layout of energy resources for case #2, when using solar thermal energy

6.3.2. Using Photovoltaic Panels

PV panels are good technology to generate electricity for the household. Sizing the PV panels is the exactly the same as in case #1.

Figure 6-33 illustrates the layout of resources of energy for case #2. Solar electricity through PV panels generates electricity which reduces grid electricity consumption. The details are explained in section 6.3.2.1. Grid electricity in smaller amounts and natural gas are conventional sources of energy for case #2 in this design.

Figure 6-33, Layout of energy resources for case #2 when using solar electricity

6.3.2.1. Energy Utilization

Based on the average electricity consumption in case #2, 36.4 kW, and the average insulation coefficient 3.53 kWh/m^2/d for the Toronto area, electricity consumption by the sun hours per day is 36.4 / 3.53 = 10.3 kW = 10,311.6 W (AC).

10,311.6 / (CEC=194) = 53 W, and 53 / (CEC=0.94) = 56, 56 is the number of PV panels; PV panels are 210 W each. Then four rows of strings with 14 panels of module 210W in each string are configured. The angles of PV panels in the four4 seasons, according to Figure 4-10, are:

Fall/Spring: Angle= Latitude = 43.7°

Summer: Angle=Latitude – 15 = 43.7 -15 = 28.7°

Winter: Angle=Latitude + 15 = 43.7 +15 = 58.7°

When the seasons change, it is strongly recommended that the PV modules be changed.

6.3.2.2. Emission Reduction

Based on previous sections in this thesis, part PV panels roughly create 56 x 210 x 90% x 3.53 = 37 kW electricity per day.

According to the calculator in the Plug into Green Canada website, in generating the average 3,892 kWh electricity per month, 3,892 kg CO_2/year was emitted into the atmosphere in Ontario. In other words, the designed PV system saves 3,892 kg CO_2/year or 46,704 kg CO_2 in 25 years of project's life; this is depicted in diagram 6-38.

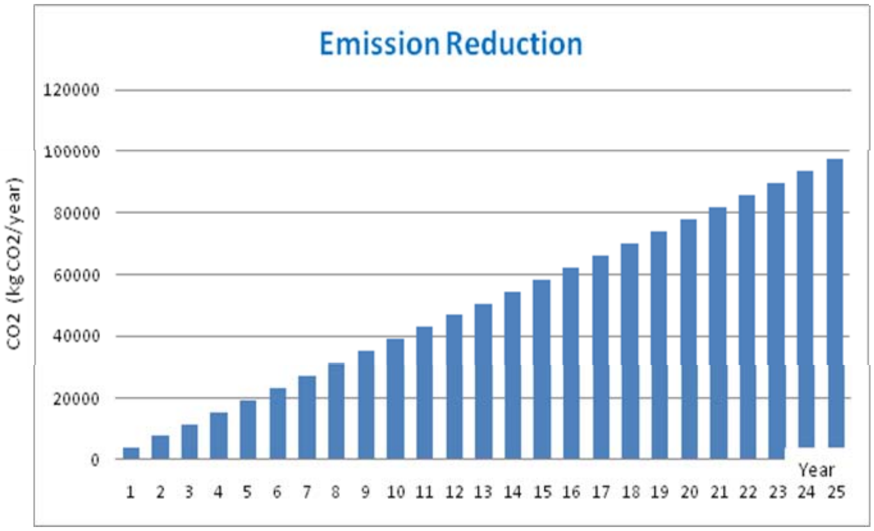


Figure 6-34, CO_2 reduction in PV panels' life for Case #2

6.3.2.3. Cost Analysis

Each solar panel SCM 210 W is $1,541.65. The cost for 56 panels is $86,332.40, plus 13% tax, for a total cost of $97,555.61. In the case of a government rebate of13% rebate, the total cost is $86,332.40.

To finding amount of the loan payment, when the principal is $86,332.40, the payment is over 10 years, N = 12 X 10 = 120, and i = 4.5%, using the standard mortgage equation (equation 5-65), the annual payment is $11,191.94.

Generating an average of 1,108 kWh/month means a saving of $136.90 per month or $1,642.80 per year, based on the present cost of electricity. The life of the PV system is 25 years. The value of savings in 25 years is calculated using the future value equation (equation 5-64), when n = 25 years, IR = 3% and Y0 = 1,642.80.

Figure 6-35 shows the summary of the financial balance for case #2. This chart shows that after 7 years, the initial cost is paid off by accumulating the savings over the years. After the 7 years, it is simply savings in the electricity bill, for the remainder of the project's life.

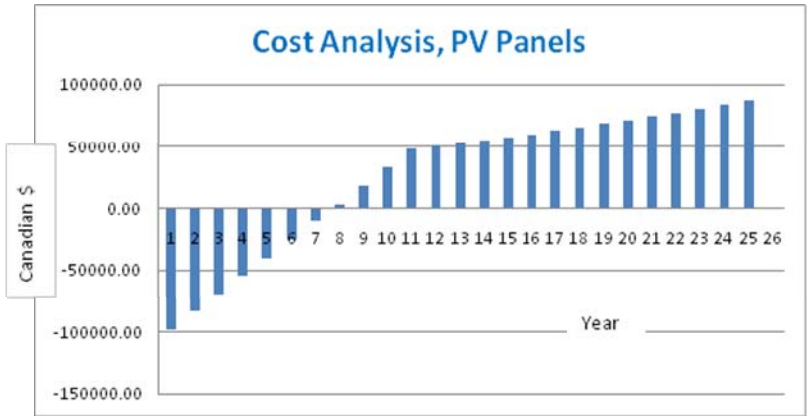


Figure 6-39, Cost summary of PV solar panels with the government rebate for case #2

The second option assumes no government incentive. Therefore, the cost of the project is \$97,555.60. With the loan principal of \$97,555.60, and using equation (5-65), the monthly payment is \$1,053.90, and the annual payment of the loan is \$12,646.89. The annual savings on the electricity bill is the same as the first option, \$1,642.80. Figure 6-36 depicts the summary of the financial balance.

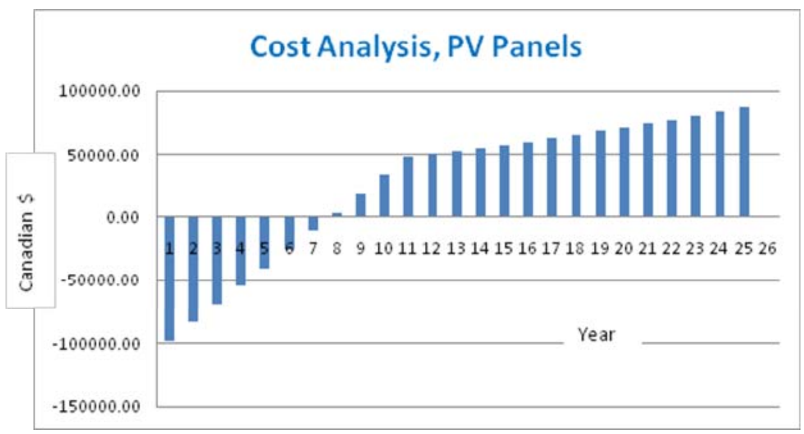


Figure 6-36, Cost summary of PV solar panels without the governmental rebate for case #2

6.3.3. Using the Geothermal System

The ground source energy system as explained in Chapter 4 is an amazing source of renewable energy, because it is “reliable”, without any interruption by Mother Nature; As well, the geothermal system cost effectively provides energy for heating and cooling the building. In this section, the geothermal system is customized for case #2 with analysis from the point of energy generation, pollution reduction and cost. Both houses in case #1 and case # 2 are very similar, and the geothermal system in both cases is the same. The calculation for energy, emissions and cost is the same as well. Figures 6-27, 6-28, and 6-29 show the energy, emission reduction and cost for case #2.

Figure 6-37 depicts the layout of case #2 when using geothermal energy as a renewable source of energy, together with conventional sources of energy - grid electricity and natural gas. By using geothermal energy, electricity consumption for heating and cooling is reduced to one-fourth. Section 6.3.2.1 depicts greater detail of the energy calculation.

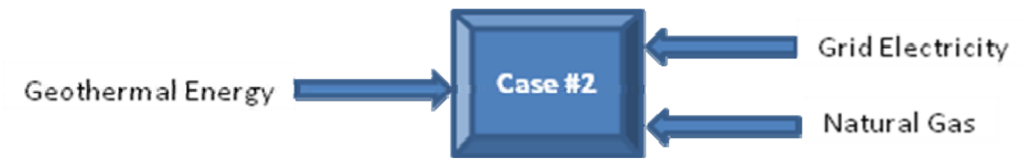


Figure 6-37, Layout of energy resources for case #2 when using geothermal energy

6.3.4. Hybrid System #1

As previously stated, geothermal energy is a reliable source of energy providing heating and cooling energy. The ground source heat pump obtains 4 units of energy from the ground by spending 1 unit of energy (electricity), and provides exactly 5 units of energy for cooling or heating purposes. Thus, the geothermal system is an ideal candidate for alternative energy from the point of reliability and efficiency. As well, this supreme technology needs only one-fifth of its energy to run the entire system.

The electricity the ground source heat pump needs can be supplied by another source of renewable energy. Then, the whole heating and cooling system would run with natural energy. This source of energy could be photovoltaic panels, which converts solar energy to electricity and can easily be built up to electricity demand level.

Figure 6-38 shows the layout of the hybrid system #2 for case #2. In this design, the geothermal energy and PV panels (solar electricity) are the source of renewable energy, and the grid electricity plus natural gas are the conventional sources of energy for case #2.

Figure 6-38, Layout of energy resources for case #2 when using hybrid system #1

Since the geothermal system is exactly the same as in case #1, the hybrid system #1 for case #2 is exactly the same as for case #1. Therefore, the energy utilization calculation, emission reduction effect and cost analysis are the same in both cases as seen in section 6.2.4.1, section 6.2.4.2, and section 6.2.4.3, respectively.

6.3.5. Hybrid System #2

The second hybrid system is defined through the solar technologies by combining PV panels for generating electricity and solar water heaters for heating the water. In the hybrid system #2, electricity and natural gas consumption is reduced. The reduction is calculated in the following paragraphs. This hybrid system is directly dependent on solar energy. In hybrid system #2, grid electricity and natural gas are still in the system as a backup for the time there is not quite enough sun available. However, for long, sunny days, extra energy overflows to the grid. Figure 6-39 depicts the layout of energy sources in case #2.

Figure 6-39, Layout of energy resources for case #2, when using hybrid system #2

6.3.5.1. Energy Utilization

Hybrid system #2 consists of solar water heaters (solar thermal) and PV panels (solar electricity). Solar water heaters are calculated in section 6.2.1.1, and PV modules are computed in section 6.3.2.1. Based on this previous assessment, the hybrid system #2 includes four panels of WSE58 for converting solar energy to 11MJ/hr, plus 56 panels of

PV modules 210W to generate 36.4 kW/day. The configuration of PV modules and the angles of panels are described in section 6.3.2.1.

6.3.5.2. Emission Reduction

With the same logic, emission reduction for hybrid system #2 is equal to emission reduction by 4 panels of WSE58, calculated in section 6.2.1.2 along with emission reduction by 56 PV modules computed in section 6.3.2.2. The quantity of emission reduction by hybrid system #2 is therefore:

1,161 + 3,892 = 5,053 kg CO_2 /year

5,053 X 25 = 126,325 kg CO_2 per 25 year of the project's life time

Figure 6-40 shows the emission reduction by hybrid system #2 in 25 years of working life.

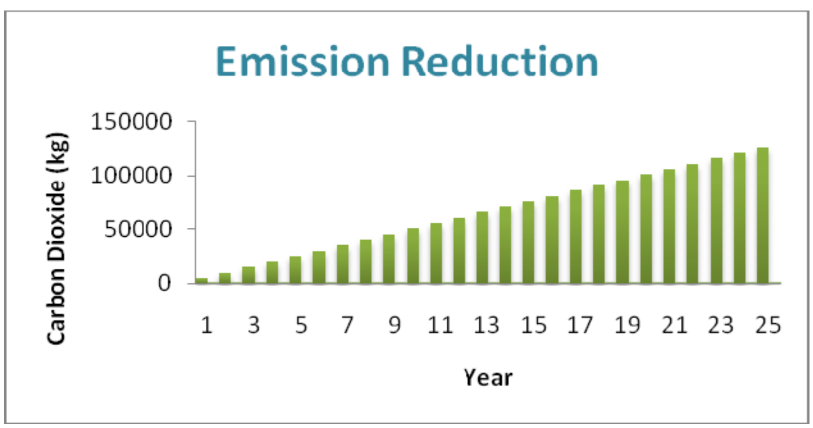


Figure 6-40, CO_2 reduction by hybrid system #2 for case #2

6.3.5.3. Cost Analysis

The cost of the hybrid system #2 is comprised of the addition of 4 solar water tubes and 56 PV modules; these costs are calculated in section 6.2.1.3 and 6.3.2.3, respectively. Thus, the cost for the hybrid system #2 is:

\$4,951.55 + \$97,555.61 = \$102,507.16

The government incentive for this project is13% at the present time, therefore the dollar value of the rebate is \$13,326.

Savings on the gas and electricity bill is (details of these savings are described in sections 6.2.2.3 and 6.3.2.1):

\$188.60 + \$136.90 = \$325.50 per month

\$325.5 X 12 = \$3,906.00 per year

The dollar value of this saving increases according to the future value equation, equation (5-64).

The first assumption computes the financial balance by considering the government incentive. The principal is then:

\$102,507.16 - \$13,326.00 = \$89,181.16

The standard mortgage equation, equation (5-65), gives the monthly payment of the loan on the initial cost, when P = 89,181.16, i = 4.5%/12 = 0.0045, and payment is in 10 years. By using the standard mortgage equation, monthly payments come to \$963.43 and the loan payment per year is \$11,561.24. The summary of the financial balance is illustrated in Figure 6-41.

The second scenario assumes no government rebate for purchasing renewable energy equipment. In this circumstance, the principal is the same as the product cost which is \$102,507.16. By using the standard mortgage equation, equation (5-65), the monthly payment of the loan is \$4,023.18 and the payment for one year is \$13,288.80 for the next 10 years. The savings on the energy bills stays the same. Figure 6-42 shows the financial balance during life of hybrid system #2.

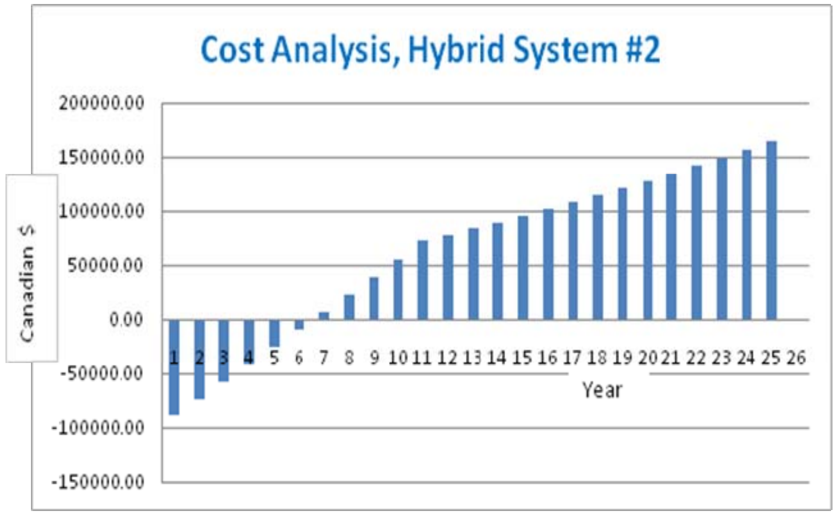


Figure 6-41, The summary of the financial balance for hybrid system #2 with governmental rebate for case #2

6.3.6. Hybrid System #3

The third combination of the hybrid system for case #2 with available technologies is the geothermal system and solar thermal energy. Ground source energy is a superior technology for heating and cooling; solar water heaters are designed for case #2 to provide domestic hot water for the household. In this system, energy consumption drastically is reduced because the main portion of energy consumption, based on Figure 6-6, which is expandable for case #2, is used for heating and cooling (57%) and hot water (17%). A total of 74% energy usage in case #2 is targeted to be reduced significantly. Grid electricity and natural gas are still sources of energy in case #2, but the amount of usage is greatly reduced. Figure 6-47 illustrates the layout of energy resources in case #2 when hybrid system #3 is in the picture as the technology for converting natural energy.

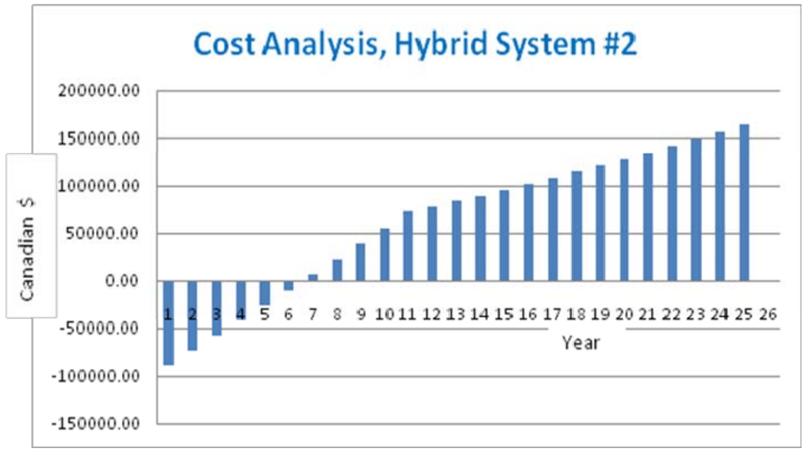


Figure 6-42, The summary of financial balance for hybrid system #2 without governmental rebate for case #2

Figure 6-47, Layout of energy resources for case #2 when using hybrid system #3

Since case #2 is very similar to case #1, and the solar thermal system (4 panels of solar water heater WSE58) and geothermal system (ground source heat pump GT049) are the same, hybrid system #3 for case #2 is the same as hybrid system #3 for case #1. Therefore, energy utilization, emission reduction, and cost analysis for hybrid system #3 for case #2 is exactly the same as hybrid system #3 for case #1, though section 6.2.6.1, section 6.2.6.2, and section 6.2.6.3 are applicable solely for case #2.

6.4. Case Study #3

Case study #3 is the central public library in Brampton, latitude 43.536, longitude -79.556. This building is categorized as a commercial building. In the commercial buildings, there is a demand for electricity to run computers, lights and appliances, and the furnaces to run the heating systems as well as generating hot water, and air-conditioning system to generate cool air in the summer. Typically, natural gas is used for heating space and water in commercial buildings.

This library is a two-storey building. The residential area is approximately 1,352 m^2, in both stories. There are many lights in the library, and computers for public use and staff use.

As case #3 is an institutional building, the pattern of energy consumption is different from cases #1 and #2. In this case, lights and computers consume a recognizable portion of energy. Figure 6-44 shows the distribution of energy consumption in case #3.

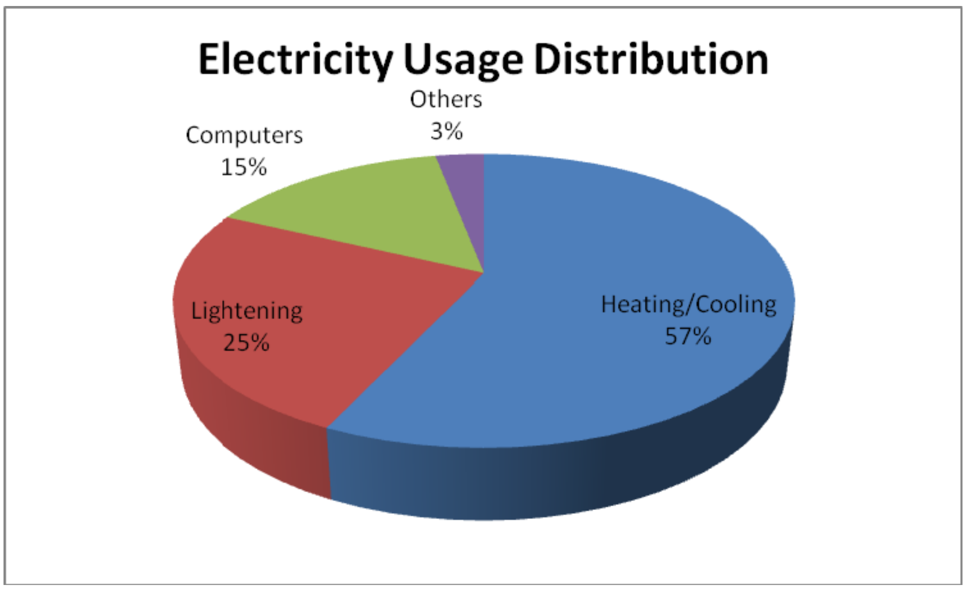


Figure 6-44, Electricity usage distribution in case #3 (Brampton Library)

Annual natural gas consumption in this library is 72,748 m^3, and average monthly consumption is 6,062.3 m^3. Figure 6-45 illustrates the distribution of the natural gas consumption in the central library.

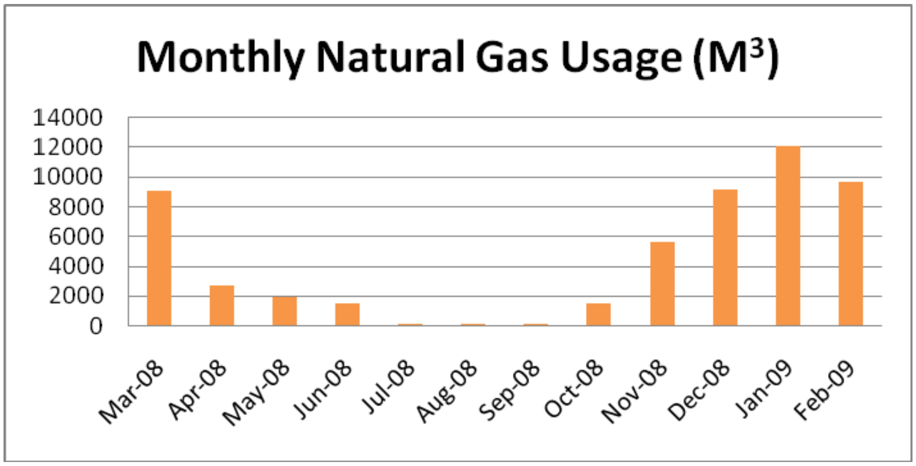


Figure 6-45, Natural gas Consumption in Brampton Library, Case #3

Electricity consumption in this library is 765,765kWh (765.8 MWh) per year, and daily consumption is 2,098kWh for this commercial building. Figure 6-51 illustrates electricity consumption in the central library.

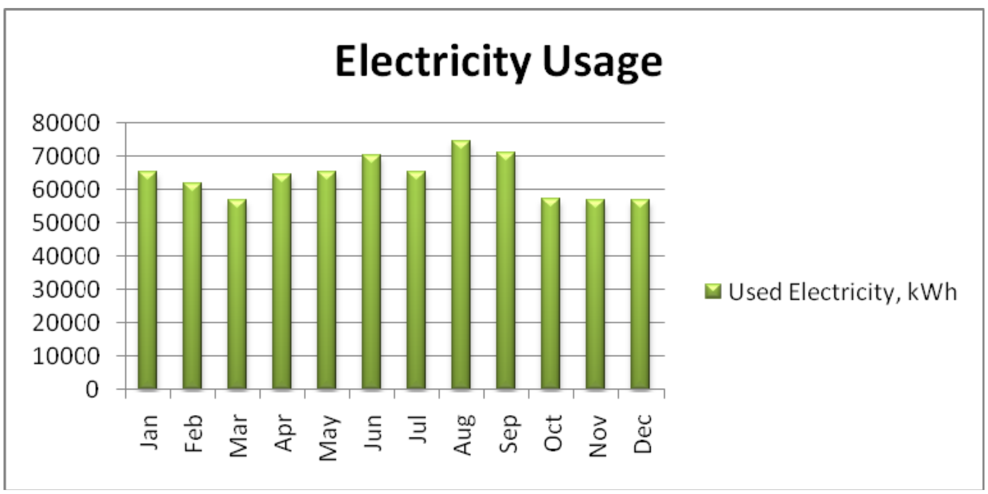


Figure 6-46, Electricity consumption in the Brampton Library, Case #3

6.4.1. Using Solar Water Heaters

Solar water heaters can be used for this building to heat the space as well as hot water. The main demand is for heating the space rather than heating the water, since it is a commercial building. Moreover, there is a large space at the back of the building and roof available for installing the solar collectors' panels.

Figure 6-47 shows the layout of energy resources for case #3. Solar thermal is the renewable source of energy together with two conventional sources of energy - grid electricity and natural gas. Using solar thermal reduces natural gas consumption as is calculated in section 6.4.1.1.

Figure 6-47, Layout of energy resources for case #3 when using solar thermal energy

6.4.1.1. Energy Utilization

Energy is calculated by using the calculator in the WSE technology website; the engine of this calculation is based on deducting the heat loss of the building by considering the isolation rate as well as the desired temperature, from the heat resulting from the solar collectors. According to this calculator, for the desired temperature of 22°C for heating space 1,352 m^2 , 58 solar collector WSE58 should be installed.

The energy generated by 58 solar collectors WSE58 is 58 x 2,741,310 = 156 MJ/h. By considering 7 hours of sun per day as the average for all days in the year, the energy produced by these solar panels is: 156 x 7 = 1,092 MJ/day

Assuming is that there are 300 days of sun per year in Canada; the energy produced by solar collectors is 327600 MJ per year. This energy can be released from 8,798.4 m^3 natural gas (201,600 MJ /37,233,949J = 8798.4), in other words, gas consumption is reduced by 8,798.4 m^3 every year. In the 25 year life span of the solar panels, this saving is 219,960.5 m^3 natural gas.

6.4.1.2. Emission Reduction

As mentioned, by releasing 1,054,350 kJ energy from natural gas, 58 kg CO_2 emits into the atmosphere. Therefore, by releasing 327,600 MJ of natural gas, 16.5 Ton CO_2 is emitted into the atmosphere. In other words, 58 solar panels prevent emitting 16.5 tons

CO_2 into the air each year; this is 412.5 Ton CO_2 in the 25 years of the panels' life. Figure 6-48 shows the CO_2 emission reduction in the 25 years of the solar panels' life.

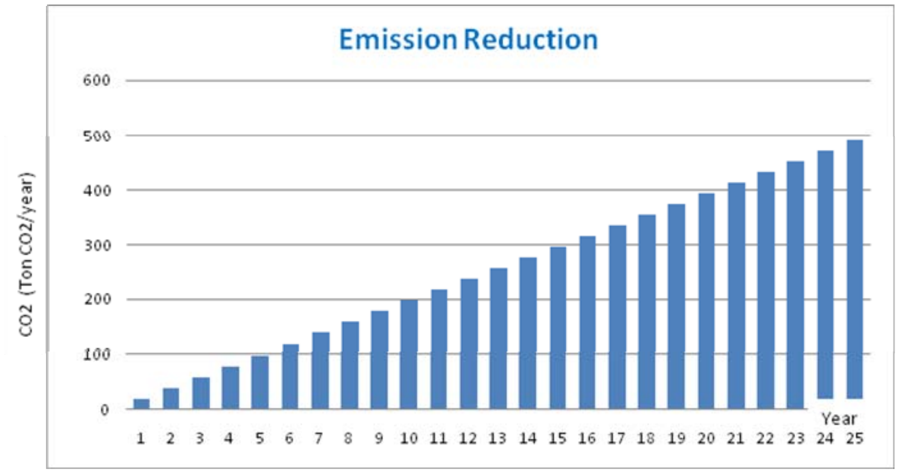


Figure 6-48, CO_2 reduction by solar panels for case #3

6.4.1.3. Cost Analysis

If there is a 13% government rebate incentive for renewable energy projects, then the calculations in this cost analysis are as follows:

The cost of the 58 solar water heater panels is $62,524.00 with the 13 % tax will add up to $70,652.12. The government incentive is estimated to be $8,128.

Saving due to the reduction of natural gas consumption is $3,858/year. This number comes from natural gas payments in last 12 months of $31,899.51 for 72,748 m^3 natural gas. The value of this saving is calculated by the future equation, equation (5-64_, when Y0=3,858, IR=3%. As the life of the equipment is 25 years, n=1 to 25, and is calculated as $Yn = 3,858\ (1.03)^n$.

The standard mortgage equation, equation (5-65), gives the monthly payment of the loan on initial cost, when P= 65,974, i = 4.5%/12 = 0.0045, and the payment is over 5 years. Using the standard mortgage equation, equation (5-65), monthly payments come to $1,191.39, and loan payments per year are $14,296.77.

Figure 6-49 displays the initial cost after two years is paid off by accumulating the saving in previous years. Afterwards, it is simply savings on the electricity bill, for the rest of the project's life.

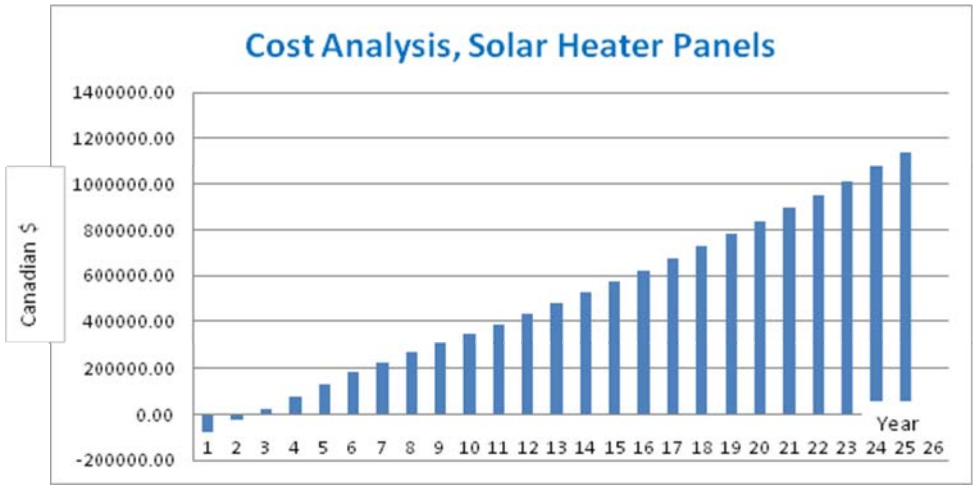


Figure 6-49, Cost summary by solar collector panels with the government rebate for case # 3

The other option is assuming there is no government incentive. The cost of these 58 solar water heater panels is $62,524, plus 13 % tax, for a total cost of $70,652.12.

The savings on the reduction of natural gas consumption is $3,858.00. This number comes from the natural gas payments over the last 12 months and equals to $31,899.51 for 72,748 m^3 of natural gas. The value of this saving is calculated by the future equation (5-64), when Y0=3858, IR=3%. As the life of the equipment is 25 years, n=1 to 25, and is calculated by $Yn = 3858\ (1.03)^n$.

The standard mortgage equation, equation (5-65), gives the monthly payment of the loan on the initial cost, when P= 70,652.12, i = 4.5%/12 = 0.0045, and the payment is over 5 years. The monthly payments then amount to $1,420.57, and the loan payment per year is $ 17,046.78.

Figure 6-50 presets the financial balance. This chart also displays that after two years, the initial cost is paid off by accumulating the savings over the previous years. Afterwards, it is simply savings on the electricity bill, for the rest of the project's life.

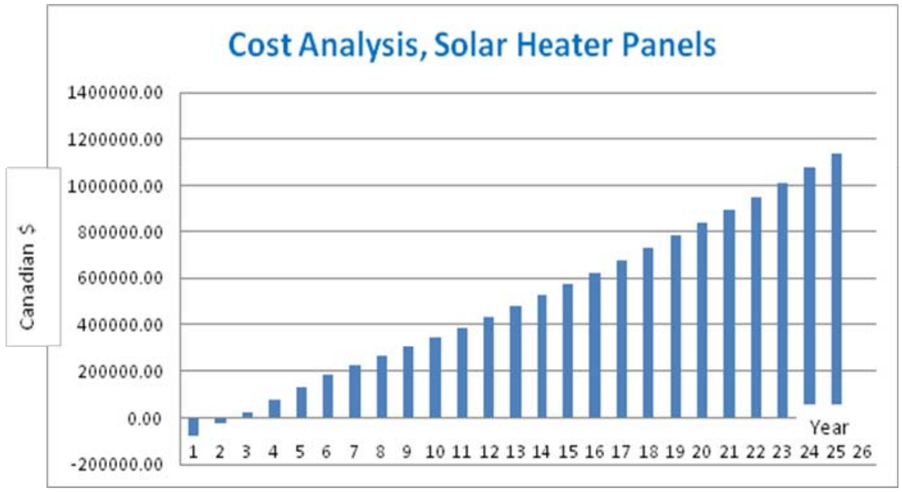


Figure 6-50, Cost summary by solar collector panels without the government rebate for case # 3

6.4.2. Using Photovoltaic Panels

PV panels are the best technology for case #3 to generate electricity because this building is located in an urban area, downtown Brampton.

Figure 6-51 illustrates the layout of resources of energy for case #3. Solar electricity through PV panels generates electricity which reduces grid electricity consumption. The details are explained in section 6.4.2.1. Grid electricity in smaller amounts and natural gas are conventional sources of energy for case #3 in this design.

Figure 6-51, Layout of energy resources for case #3 when using solar electricity

6.4.2.1. Energy Utilization

The average daily electricity consumption in case #3 is 2,098kWh, and the average insulation coefficient 3.53 kWh/m^2/d in Toronto area, electricity consumption by the sun hours per day would be 2,098 / 3.53 = 594 kW = 594,000 W (AC)

594,000/ (CEC=194) = 3061 W, and 3,061 / (CEC=0.94) = 3257, 3257 is the number of PV panels; PV panels are 210 W each. Before going further for arrange the array the availability of the installation space should be assessed.

The area of each panel is 0.9 x 1.7 = 1.53 m^3. Roof of the building is the installation area. Available area on the roof is 13 x 22 = 286 m^3. For ease of maintenance every 10 panels in form of 2 x 5 places on one mount. Figure 6-52 shows the configuration of 10 modules in one mount.

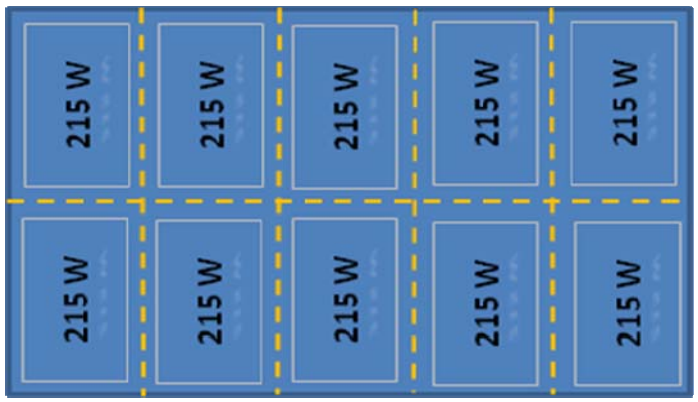


Figure 6-52, Placing 10 modules in one mount

Then the area of each mount contain 10 PV modules would be 5 X 3.4 = 17 m^2. From each side 0.2 m will be added for maintenance purposes, and then the area of each mount comes to 5.4 x 3.8 = 20.52 m^2. Figure 6-53 illustrates a mount dimension and surrounded area.

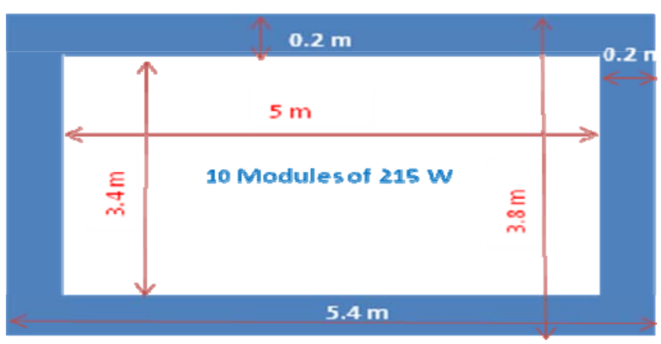


Figure 6-53, Dimensions on a mount. Blue area is considered for maintenance needs

On the roof with dimensions of 13 m by 22 m, 10 mounts can be installed, and each mount contain 10 PV panels, then 10 x 10 = 100 PV modules 215 W will generate electricity for the library. The layout for the roof design is depicted in Figure 6-54.

Figure 6-54, Layout of mounts on the roof of the library.

Then the electricity generated from these 100 modules would be:

100 x 215W x 90% x 3.53h = 68,305 Wh /day or 68,305 x 365 / 10^6= 25 MWh / year

Photovoltaic panels should have the right angle toward sun for getting the maximum solar energy, and then the angles for each season would be as follows (according to Figure 4-10):

Fall/Spring: Angle= Latitude = 43.5°

Summer: Angle=Latitude – 15 = 43.5 -15 = 28.5°

Winter: Angle=Latitude + 15 = 43.5 +15 = 58.5°

By changing the season for getting the maximum energy from the sun, changing the PV modules is strongly recommended.

6.4.2.2. Emission Reduction

Following the last section PV panels generate 2,083kWh per month. According to the calculator in Plug into Green Canada website for generating the average 2,083 kWh electricity per month, 7,312 kg CO_2/year is emitted into the atmosphere in Ontario. In other word, the designed PV system saves 182.8 Ton CO_2 in 25 years of project's life; this is depicted in Figure 6-55.

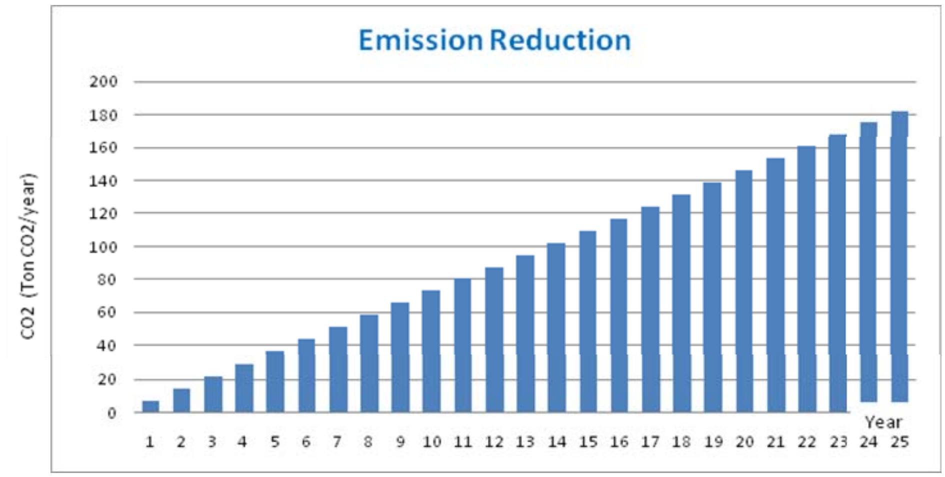


Figure 6-55, CO_2 reduction in by solar panels for Case # 3

6.4.2.3. Cost Analysis

Each Solar Panel SCM 215 W is $1,578.62 and total cost for 100 panels is $15,7862, as this is a large order, 5% discounts comes from module seller, then the total cost comes to $149,968.9. 13% tax will be added on top of this price, $169,464.86. In the case government considers 13% rebate the total cost is $149,968.9.

For finding the loan payment, the principal is 149,968.9, payment is in 10 years, N = 12 X 10 = 120 and i = 7%/12, by using Standard Mortgage equation (equation 5-65), monthly payment comes to $1,620.14 and annual payment is $19,441.63.

Generating the average of 2,083 kWh/month means saving of $257.37 per month or $3,088.40 per year based on present cost of electricity. The life of PV system is 25 years. The value of savings in 25 years can be calculated by future value equation (equation 5-64), when n = 25 years, IR = 3% and Y0 =3,088.40.

Figure 6-56 presets two slopes which are represents of two equations. Also, this chart displays that after 7 years the initial cost will be paid off by accumulating the saving per previous years. Afterward, is just saving over the electricity bill, for the rest of the project's life.

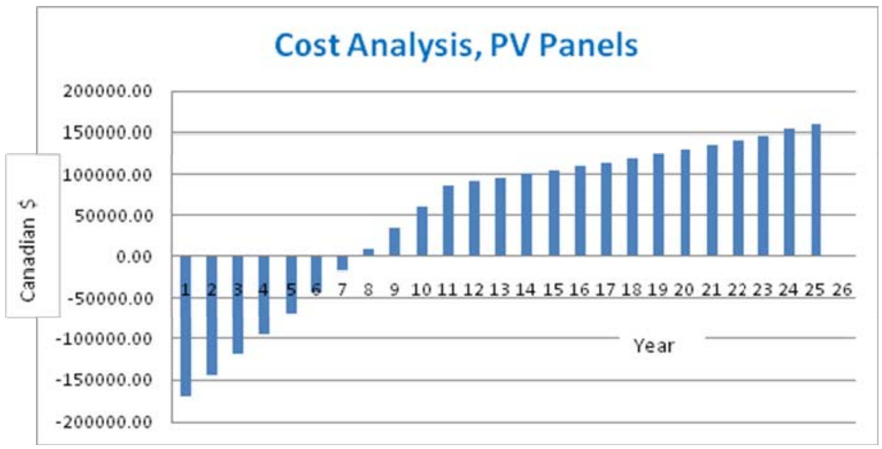


Figure 6-56, Cost summary by PV solar panels with Governmental rebate for case #3

By eliminating governmental incentive, the second assumption in cost calculation will be completed. As mentioned, each Solar Panel SCM 215 W is $1,578.62 and total cost for 100 panels is $15,7862, since this is a large order, 5% discounts comes from module seller, then the total cost comes to $149,968.9. 13% tax will be added on top of this price, $169,464.86.

For finding the loan payment, the principal is 169,464.86, payment is in 10 years, N = 12 X 10 = 120, and i = 7%/12, by using Standard Mortgage equation (equation 5-65), monthly payment comes to $1830.75 and annual payment is $21,969.04.

Generating the average of 2,083 kWh/month means saving of $257.37 per month or $3,088.40 per year based on present cost of electricity. The life of PV system is 25 years. The value of savings in 25 years can be calculated by future value equation (equation 5-64), when n = 25 years, IR = 3% and Y0 =3,088.40.

Figure 6-57 shows financial balance. Also, this chart displays that after 7 years the initial cost will be paid off by accumulating the saving per previous years. Afterward, is just saving over the electricity bill, for the rest of the project's life.

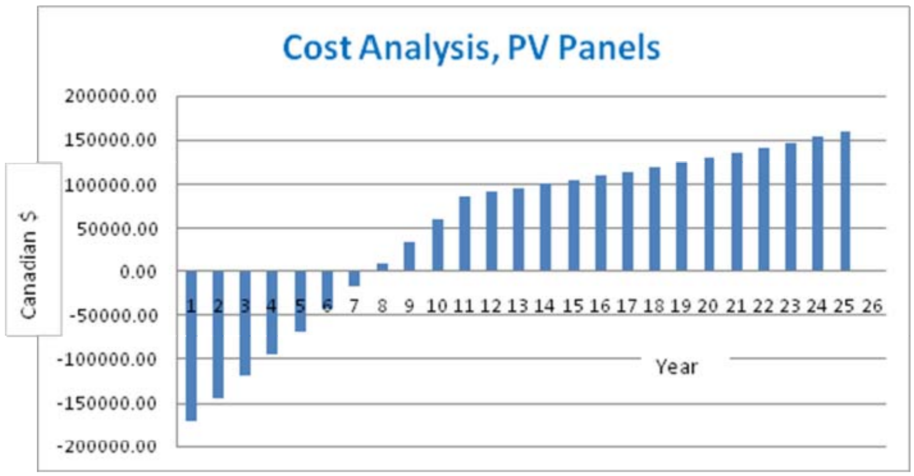


Figure 6-57, Cost summary by PV solar panels without Governmental rebate for case #3

6.4.3. Using Geothermal System

Ground source energy system as a source of renewable energy with high performance (the average coefficient of performance (COP) of a Ground source energy system is 4) is an amazing source of renewable energy. Geothermal system cost effectively provides energy for heating and cooling the building. This system can be a reasonable source of energy for heating and cooling case #3. According to Figure 6-49 energy for heating and cooling the library is 57% which is equal to 436.5 MW. By considering COP=4, 436.5 MW reduces to 87.3 MW.

Figure 6-58 depicts the layout of case #3 when using geothermal energy as a renewable source of energy beside conventional source of energy, grid electricity and natural gas. By using geothermal energy electricity consumption for heating & cooling will reduced to one fifth.

Figure 6-58, Layout of energy resources for case #3, when using geothermal energy

For sizing the ground source heat pump heat loss of the building and heating/cooling load of the building is needed, because geothermal system should provide enough energy for heating/cooling plus overcome the heat loss of the building. Since there is not enough information for case #3, sizing the ground source heat pump cannot proceed further.

6.4.4. Hybrid System #1

Following section 6.4.3 ground source heat pump needs one fifth energy in form of electricity to generate heating/cooling energy for case #3. The electricity ground source heat pump needs can be supplied by another source of renewable energy. Then, whole heating and cooling system would run with natural energy. This source of energy could be photovoltaic panels, which convert solar energy to electricity and easily it can be built up to electricity demand level. Hybrid system #1 is combination of ground source heat pump plus PV modules.

Figure 6-59 shows the layout of hybrid system #1 for case #3. In this design geothermal energy and PV panels (Solar Electricity) are the source of renewable energy, and grid electricity plus natural gas are the conventional sources of energy for case #3.

Figure 6-59, Layout of energy resources for case #3, when using hybrid system #1

Since the geothermal system was not sized in section 6.4.3, because of information missing, the hybrid system #1 for case #3 cannot be sized in this section, then.

6.4.5. Hybrid System #2

The second hybrid system can be defined by the solar technologies through combining PV panels for generating electricity and solar water heaters for heating the space. In hybrid system #2 electricity and natural gas consumption will be reduced. The reduction will be calculated in the following paragraphs. This hybrid system would be directly dependent on solar energy. In hybrid system #2, still grid electricity and natural gas are in the system as a backup system for the time there is not quite enough sun in the sky. Figure 6-60 depicts the layout of energy sources in case #3.

Figure 6-60, Layout of energy resources for case #3, when using hybrid system #2

6.4.5.1. Energy Utilization

Hybrid system #2 is consisting of solar water heaters (Solar Thermal) and PV panels (Solar Electricity). Solar water heaters were calculated in section 6.4.1.1, and PV modules were computed in section 6.4.2.1. Based on this previous assessment hybrid system #2 is including 58 panels of WSE58 as solar thermal energy for converting solar energy to 156 MJ/hr, plus 100 panels of PV modules 215 W for generating 68.3 kW/day. The configuration of PV modules and the angles of panels are described in section 6.4.2.1.

6.4.5.2. Emission Reduction

With same logic emission reduction for hybrid system #2 is equal to emission reduction by 58 panels of WSE58 which was calculated in section 6.4.1.2 along with emission reduction by 100 PV modules, which was computed in section 6.4.2.2. Then, the quantity of emission reduction by hybrid system #2 is:

16.5 + 7.3 = 23.8 Ton CO_2 /year

23.8 X 25 = 595 Ton CO_2 per 25 year project life time

Figure 6-61 shows the emission reduction by hybrid system #2 in 25 years of working life.

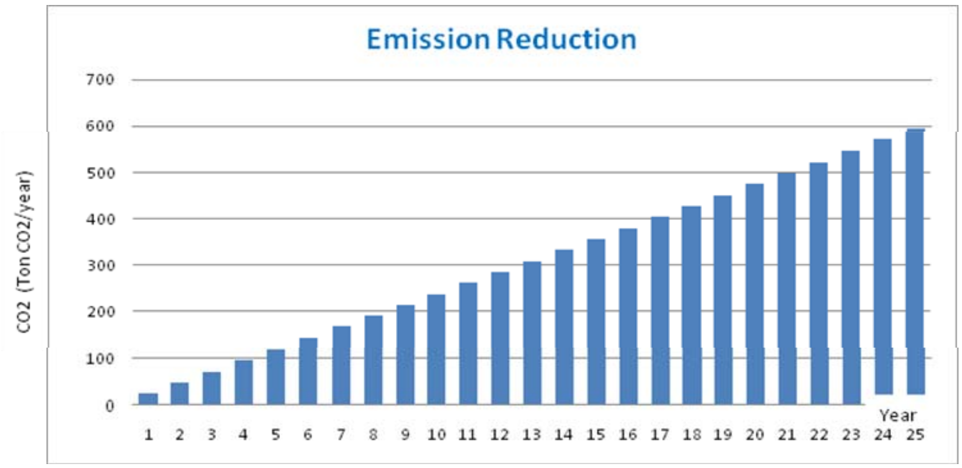


Figure 6-61, CO_2 reduction by hybrid system #2 for case #3

6.4.5.3. Cost Analysis

Cost of the hybrid system #2 is the addition of 58 solar water tubes and 100 PV modules; these costs were calculated in section 6.4.1.3 and 6.4.2.3 respectively. Then, the cost for the hybrid system #2 would be:

$70,652.12+ $169,464.68= $240,116.8

Government incentive for this project would be 13% at present time, and then the dollar value of the rebate is $27,624.1.

Saving over gas bill and electricity bill is (details of these savings are described in sections 6.4.1.3 and 6.4.2.3):

$3,858 + $3,088.3= $6,946.4 per year

The dollar value of this saving will be increase according to future value equation, equation 5-64.

The first assumption is computing the financial balance by considering governmental incentive. Then, the principal would be:

$240,116.8 - $27,624.1 = $212,492.7

Standard Mortgage equation, equation 5-65, gives the monthly payment of the loan on initial cost, when P = 212,492.7, i = 4.5%/12 = 0.0045, and payment is in 10 years. Monthly payments come to $2,295.59, and loan payment per year is $27,574.07. The summary of the each year balance are illustrated in Figure 6-62 as follow:

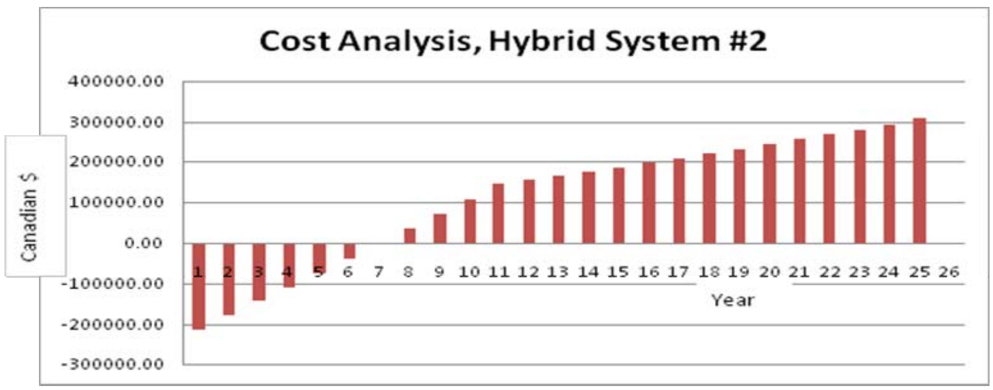


Figure 6-62, The summary of financial balance for hybrid system #2 with governmental rebate for case #3

The second assumption is when there is no governmental rebate for purchasing renewable energy equipment. In this circumstance, principal is $240,116.8. Then, by replacing in Standard Mortgage equation, equation 5-65, monthly payment of the loan is $2594.01 and payment for a year is $31128.2 for 10 years. Financial calculations for each year are summarized in Figure 6-63.

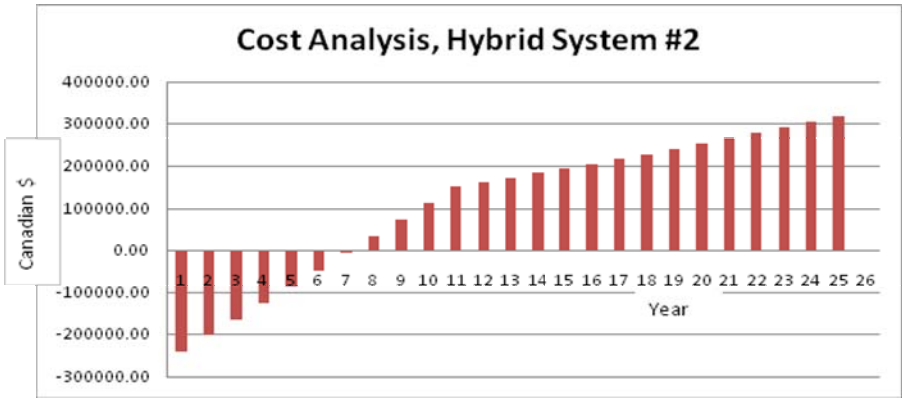


Figure 6-63, The summary of financial balance for hybrid system #2 without governmental rebate for case #3

6.5. Case Study #4

Case study # 4 is a plastic injection company in Mississauga, latitude 43.640 and longitude -79.622. This building can be categorized as the industrial building. The specification of industrial buildings is high energy consumption. Industrial buildings are high in using electricity over running the machines and production equipment. These machines produce some heat as well. There is not a great demand for hot water; however there is great need for heating the building.

The area of this industrial unit is 1,900 m^2 (30 x 63.3); there are 100 employees, some working on floor and some are in office space, they are working 5 days per week and each day for 16 hours. 24 computers are on all the time, and average load of each computer is 200 W. Lighting load is 10 W/m^2 , for 100 h/W. For the 12 months electricity usage was 1320 MWh, and then the monthly average electricity consumption comes to 110MWh. Figure 6-64 shows the electricity usage in this company in each month. Since the major electricity users are machine and company runs with the same schedule, the electricity consumption is almost the same in each month.

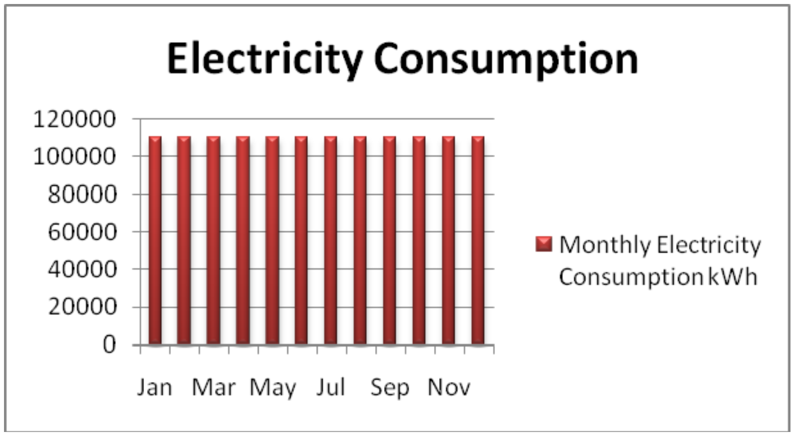


Figure 6-64, Electricity consumption in injection plastic company, Case #4, (Monthly bills)

As case #4 is an industrial building, the energy consumption pattern is totally different from prior cases. In this case machines including computers have the highest portion of electricity consumption. Figure 6-65 illustrates energy case age distribution in case #4.

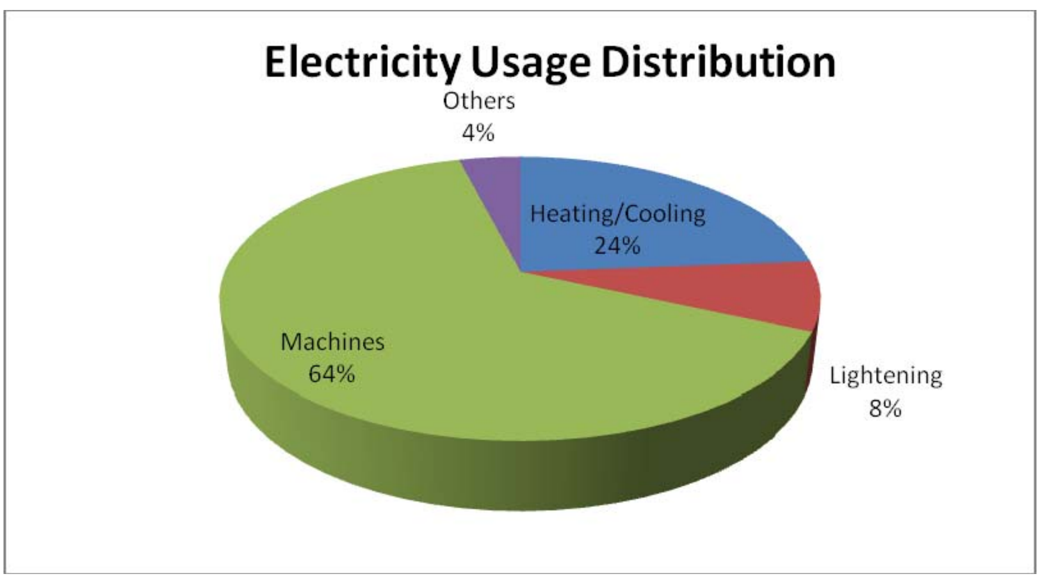


Figure 6-65, Electricity usage distribution for case #4 (Case #4 information)

Also, the natural gas consumption in last 12 months was 43,000 m^3. The information for monthly usage of natural gas is not available.

6.5.1. Using Solar Water Heaters

Solar water heater can be used for this industrial building to heat the space as well as hot water. There is a big space on back of the building and roof available for installing the solar collectors' panels.

Figure 6-66 shows the layout of energy resources for case #4. Solar thermal is the renewable source of energy beside two conventional sources of energy, grid electricity and natural gas. Solar thermal reduced natural gas consumption as will be calculated in section 6.5.1.1.

Figure 6-66, Layout of energy resources for case #4, when using solar thermal energy

6.5.1.1. Energy Utilization

By using the calculator in WSE technology website; for heating this company with 1,900 m^2 for desired temperature 22°C, 75 solar collectors WSE58 are needed.

The Energy generated by 75 solar collectors WSE58 is 75 x 2,741,310 = 205.6 MJ/h. By considering 7 hours of sun per day as average for all days in the year, the energy produced by these solar panels would be: 205.6 x 7 = 1,439.2 MJ/day

The assumption is that there are 300 days of sun per year in Canada. Then, the energy produced by solar collectors is 431,760 MJ per year. This energy can be released from 11,606 m^3 natural gas (431,760 MJ /37,233,949J = 11606.4), in other word gas consumption reduced 11,606 m^3 every year. In 25 years life of the solar panels this saving is 290,161 m^3 natural gas.

6.5.1.2. Emission Reduction

As mentioned by realising 1,054,350 kJ energy from natural gas, 53 kg CO_2 emits into the atmosphere. Then, by getting 431,760 MJ energy from natural gas, 21.7 Ton CO_2 emits into the atmosphere. In other word, 75 solar panels prevent emitting 21.7 Ton CO_2 into air each year; this will be 542.5 Ton CO_2 in 25 years panels' life.

Figure 6-67 shows the CO_2 emission reduction in 25 years solar panels' life.

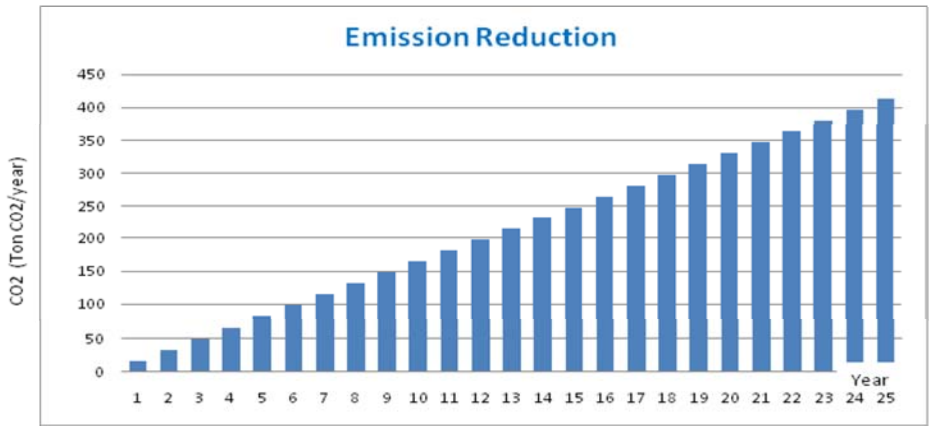


Figure 6-67, CO_2 reduction in 25 years solar panels' life, Case #4

6.5.1.3. Cost Analysis

The first assumption is 13% governmental incentive for renewable energy project. Then, the calculations are as follow:

The cost of these 75 solar water heater panels is \$80,850, plus 13 % tax the total cost would be \$91,360.50. The government incentive is about \$10,510.50.

This injection company pays \$0.41 for each 1 $\mathbf{m^3}$, therefore saving over the reduction of 11,606 $\mathbf{m^3}$ natural gas is \$4,758.46. The value of this saving is calculated by future equation, when Y0=4758.46, IR=3%, as the life of the equipment is 25 years, n=1 to 25. Although, calculating is through $Yn = 4{,}758.46\ (1.03)^n$.

Standard Mortgage equation, equation 5-65, gives the monthly payment of the loan on initial cost, when P=80,850, i = 4.5%/12 = 0.0045, and payment is in 5 years. Monthly payments come to $1,540.6, and loan payment per year is $18,487.

Figure 6-68 displays after 4 years the initial cost will be paid off by accumulating the saving per previous years. Afterward, is just saving over the electricity bill, for the rest of the project's life.

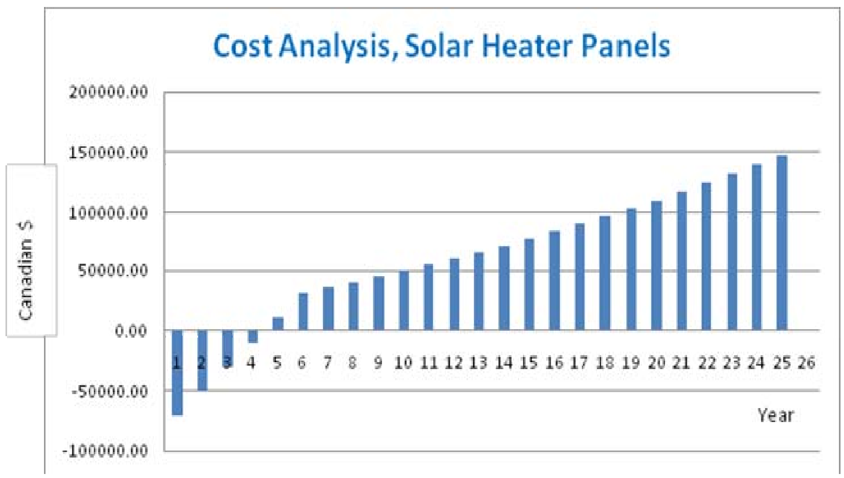


Figure 6-68, Cost summary by solar heater panels with Governmental rebate for case #4

The second assumption is when there is no governmental incentive. Then, the cost of these 75 solar water heater panels is $80,850, plus 13 % tax the total cost would be $91,360.50.

This injection company pays $0.41 for each 1 m^3, and then saving over the reduction of 11,606 m^3 natural gas is $4,758.46. The value of this saving is calculated by future equation, equation 5-64, when Y0=4,758.46, IR=3%. As the life of the equipment is 25 years, n=1 to 25. Although, calculating is through $Yn = 4{,}758.46\,(1.03)^n$.

Standard Mortgage equation, equation 5-65, gives the monthly payment of the loan on initial cost, when P=91,360.50, i = 4.5%/12 = 0.0045, and payment is in 5 years. Monthly payments come to $ 1,346.279, and loan payment per year is $ 16,155.35.

Figure 6-69 presents after 4 years the initial cost will be paid off by accumulating the saving per previous years.

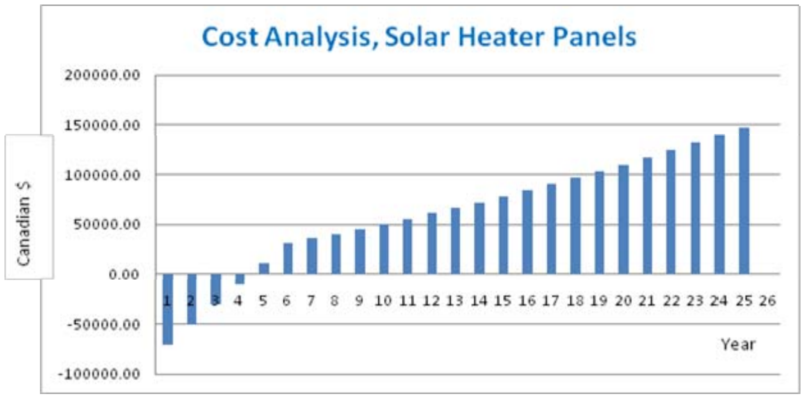


Figure 6-69, Cost summary by solar heater panels without Governmental rebate for case #4

6.5.2. Using Photovoltaic Panels

The average electricity consumption in case #4 is 110,000kWh, generating this much electricity with the average insulation coefficient 3.53 kWh/m2/d for Toronto area resulted in having thousands of PV modules, which is not reasonable decision. Because, that many PV panels demand huge area to stand, this area is not available for the injection company. Moreover, the maintenance of so many PV panels is very costly. Maintenance for PV modules is included in adjusting the angle toward sun 4 times per year, plus cleaning the snow of the panels in long Canadian winter, though PV modules will be chosen based on available space on the roof of the building.

Figure 6-70 illustrates layout of resources of energy for case #4. Solar electricity through PV panels generates electricity which reduces grid electricity consumption. The details are explained in section 6.5.2.1. Grid electricity in smaller amount and natural gas are conventional sources of energy for case #4 in this design.

Figure 6-70, Layout of energy resources for case #4, when using solar electricity

6.5.2.1. Energy Utilization

The area on the roof of this injection company is 30 m x 63.3 m. The actual available area for PV panels is 30 x 50 = 1,500 m^2. In this instance, sizing the PV panels is based on vacant space on the roof.

Every 10 PV panels are placed together on a mount with a dimension of 5m x 3.8 m; considering 0.2 m from each side for maintenance, the actual space for each mount is 5.4m x 3.8m. Figure 6-52 depicts a sketch of a mount containing 10 PV panels. Figure 6-53 illustrates a schematic picture of a mount with related dimensions.

The best arrangement of the mounts on the roof is 5 x 13 which comes to a total of 65 mounts, with each mount containing 10 panels. 650 PV panels then generate electricity for the injection company. The electricity generating from 650 modules 215 W is roughly 215 x 650 x 90% x 3.53 = 443,985.8 W/ day = 444 kW/day.

Figure 6-71 depicts the configuration of 650 modules on the roof of the injection plastic company.

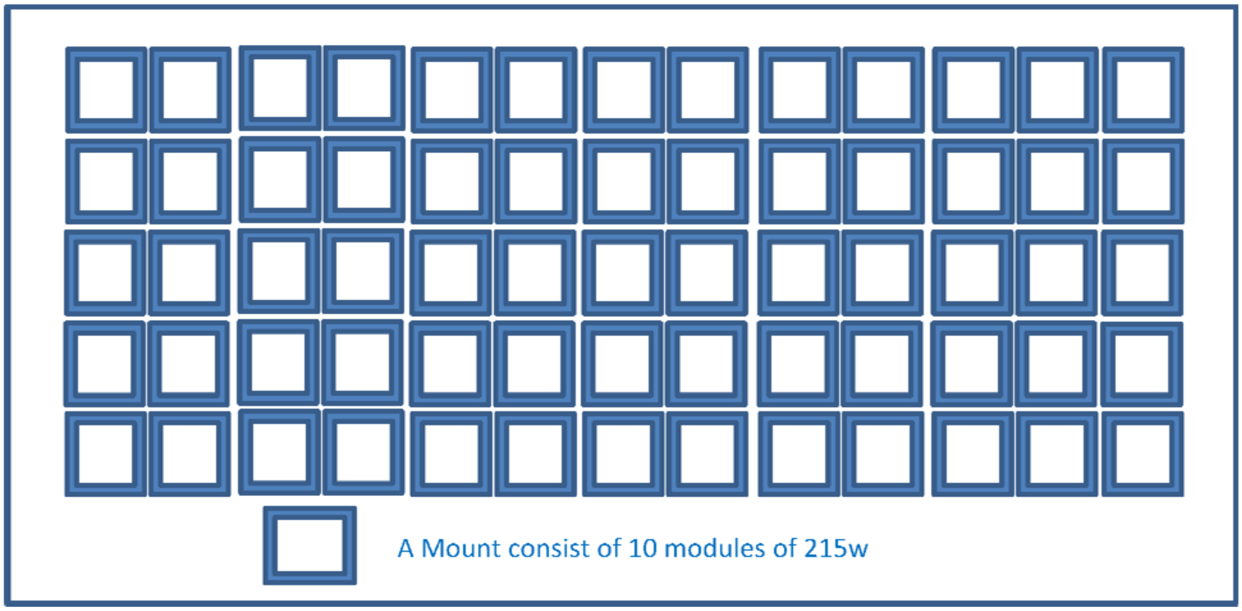


Figure 6-71, The configuration of the PV modules on the roof of the injection plastic company, case #4

Photovoltaic panels should have the right angle towards sun for getting the maximum amount of solar energy. The angle for each season is then (According to Figure 4-10):

Fall/Spring: Angle= Latitude = 43.6°

Summer: Angle=Latitude – 15 = 43.6 -15 = 28.6°

Winter: Angle=Latitude + 15 = 43.6 +15 = 58.6°

As the seasons change, it is strongly recommended the PV modules be changed in order to get the maximum energy from the sun.

6.5.2.2. Emission Reduction

The energy generated by 650 modules is 13.5 MW/month. This means the injection company uses 13.5 MW less electricity each month. These PV modules save the environment from 47,391 kg CO_2/year, in accordance with the calculator in the Plug into Green Canada's website. During 25 year lifespan of the modules, 1,184.8 Ton CO_2

emissions are reduced. Figure 6-72 illustrates the emission reduction in 25 years when using the PV panels.

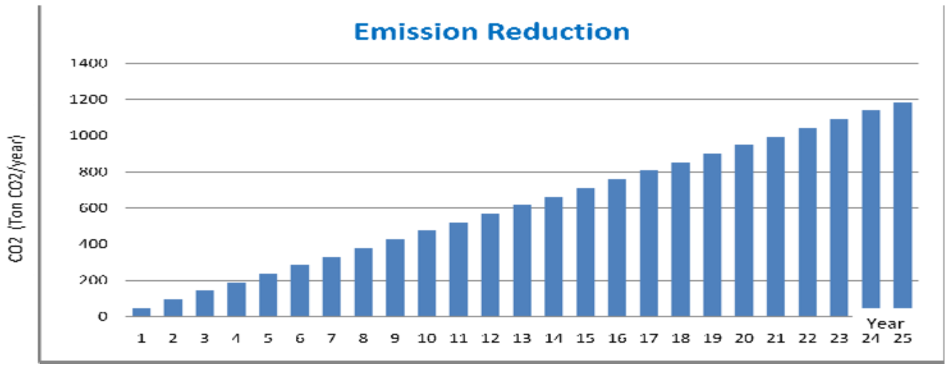


Figure 6-72, CO2 reduction by years PV panels for case #4

6.5.2.3. Cost Analysis

Each solar panel SCM 215 W is $1,578.62, with the cost for 650 panels being $1,026,103.00. As this is a large order, 10% discounts comes from the module seller, thereby lowering the cost to $923,492.70. 13% tax is, for a total price of $1,043,546.75. In case the government considers a 13% rebate, the cost is $120,054.00.

To find the loan payment, the principal is $149,968.90 the, payment is over 10 years where N = 12 X 10 = 120, and i = 7%/12. Using the standard mortgage equation (equation 5-65), the monthly payment comes to $9,976.62 and annual payment is $119,719.50.

This injection company pays $0.103 for each 1 kW, and savings with the reduction of electricity, 444 x 365, is $16,692.18. The value of this saving is calculated by the future equation, equation (5-64), when Y0=$16,692.18, and IR=3%. As the life of the equipments is 25 years, n=1 to 25, therefore the calculation is .

Figure 6-73 displays that after 7 years, the initial cost is paid off by accumulating the saving over the previous years. After this period, it is simply savings on the electricity bill for the remainder of the project's life.

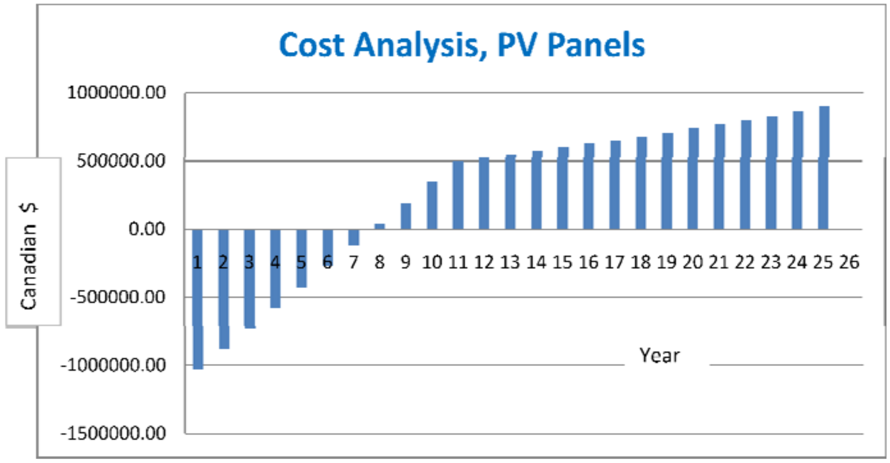


Figure 6-73, Cost summary by PV panels with the government rebate for case #4

Eliminating the government incentive is the second option in the cost analysis. Each solar panel SCM 215 W is \$1,578.62, with a total cost for 650 panels being \$1,026,103.00. Since this is a large order, 10% discounts come from the module seller, giving a total cost of \$923,492.70; 13% tax is added, for a final price of \$1,043,546.75.

To find the loan payment, the principal is \$1,043,546.75, payment is over 10 years, then N = 12 X 10 = 120 and i = 7%/12. Using the standard mortgage equation (equation 5-65), the monthly payment comes to \$11,273.59 and the annual payment is \$135,283.03.

This injection company pays \$0.103 for each 1 kW, with savings from the reduction of electricity 444 x 365 being \$16,692.18. The value of this saving is calculated by the future equation (5-64) when Y0=16,692.18, IR=3%. The life of the equipment is 25 years, so n=1 to 25, and calculates .

Figure 6-74 displays that after 7 years, the initial cost is paid off by accumulating the saving over previous years. Going forward, it is simply savings on the electricity bill for the remainder of the project's life.

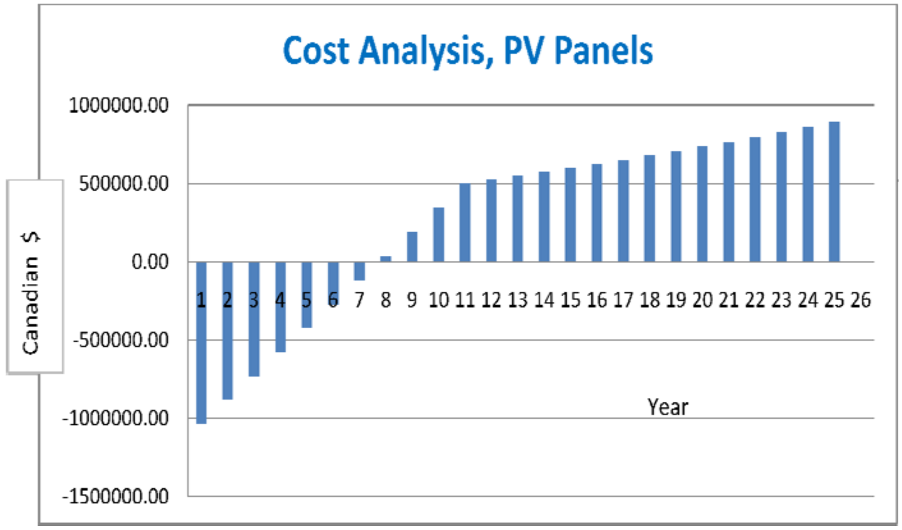


Figure 6-74, Cost summary by PV panels without the government rebate for case #4

6.5.3. Using the Geothermal System

The ground source heat pump as a source of renewable energy with high performance (the average coefficient of performance (COP) of a ground source energy system is 4) is an amazing source of renewable energy. This system is a reasonable source of energy for heating and cooling case #4. According to Figure 6-70, the energy for heating and cooling the injection plastic company is 24%, which is equal to 316.8 MW. By considering COP=4, 316.8 MW reduces to 63.4 MW.

Figure 6-75 depicts the layout of case #4 when using geothermal energy as a renewable source of energy besides the conventional sources of energy grid electricity and natural gas. By using geothermal energy, electricity consumption for heating and cooling is reduced to one-fifth.

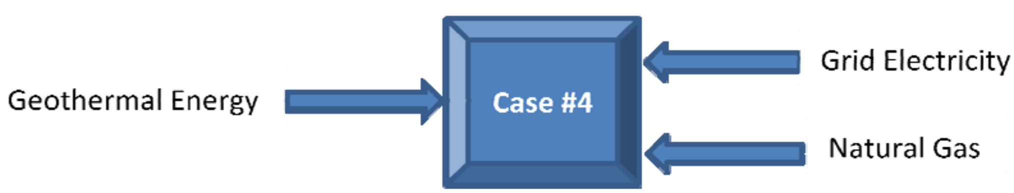


Figure 6-75, Layout of energy resources for case #4 when using geothermal energy

For sizing, the ground source heat pump's heat loss of the building and heating/cooling load of the building is needed because the geothermal system should provide enough energy for heating/cooling plus overcome the heat loss of the building. Since there is not enough information for case #4, sizing the ground source heat pump cannot proceed further.

6.5.4. Hybrid System #1

Following section 6.5.3, ground source heat pump needs one fifth the energy in the form of electricity to generate heating/cooling energy for case #4. The needed electricity by the ground source heat pump can be supplied by another source of renewable energy. Then the entire heating and cooling system would run with natural energy. This source of energy could be photovoltaic panels, which convert solar energy to electricity and can easily be built up to electricity demand level. Hybrid system #1 is a combination of ground source heat pump plus PV modules.

Figure 6-76 shows the layout of hybrid system #1 for case #4. In this design, geothermal energy and PV panels (solar electricity) are the source of renewable energy, and the grid electricity plus natural gas are the conventional sources of energy for case #4.

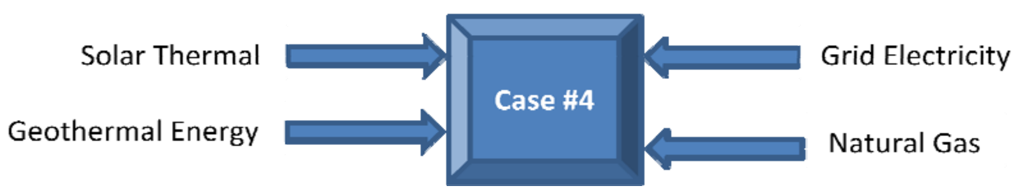


Figure 6-76, Layout of energy resources for case #4 when using hybrid system #1

Since the geothermal system is not sized in section 6.5.3 because of missing information, the hybrid system #1 for case #4 cannot be sized in this section either.

6.5.5. Hybrid System #2

The second hybrid system is defined by the solar technologies through combining PV panels for generating electricity and solar water heaters for heating the space. In hybrid system #2, electricity and natural gas consumption is reduced. The reduction is calculated in the following paragraphs. This hybrid system is directly dependent on solar energy. In hybrid system #2, grid electricity and natural gas are still in the system as a backup for the time there is not quite enough sunshine. Figure 6-77 depicts the layout of energy sources in case #4.

Figure 6-77, Layout of energy resources for case #4, when using hybrid system #2

6.5.5.1. Energy Utilization

Hybrid system #2 consists of solar water heaters (solar thermal) and PV panels (solar electricity). Solar water heaters are calculated in section 6.5.1.1, and PV modules are computed in section 6.5.2.1. Based on previous assessments, hybrid system #2 includes 72 panels of WSE58 as the solar thermal energy source to convert solar energy to 205.6 MJ/hr, plus 650 panels of PV modules of 215 W to generate 444 kW/day. The configuration of the PV modules and the angles of the panels are described in section 6.5.2.1.

6.5.5.2. Emission Reduction

Emission reduction for hybrid system #2 is equal to emission reduction by 72 panels of WSE58 (section 6.5.1.2), plus emission reduction by 650 PV modules (section 6.5.2.2). Hence, the quantity of emission reduction by hybrid system #2 is:

21.7 + 47.4 = 69.1 Ton CO_2 /year

69.1 X 25 = 1,727.5 Ton CO_2 per 25 year project life time

Figure 6-78 shows the emission reduction by hybrid system #2 in 25 years of working life.

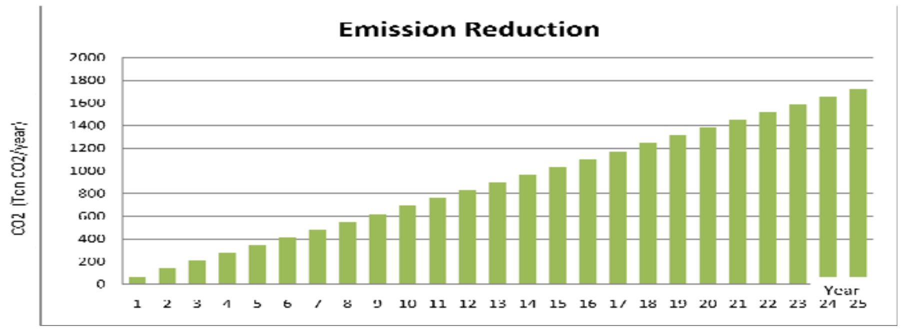


Figure 6-78, CO_2 reduction by hybrid system #2 for case #4

6.5.5.3. Cost Analysis

The cost of the hybrid system #2 is the addition of 75 solar water tubes and 650 PV modules; these costs are calculated in section 6.5.1.3 and 6.5.2.3, respectively. Therefore, the cost for the hybrid system #2 is:

$91,360.50 + $1,043,546.75 = $1,134,907.3

Government incentive for this project is 13% at the present time, making the dollar value of the rebate $130,564.50.

Savings o gas and electricity bills are as follows (details of these savings are described in sections 6.4.1.3 and 6.5.2.3):

$4,758.46+ $16,692.18 = $21,450.6 per year

The dollar value of this savings increases according to the future value equation, equation (5-64).

The first option assumes computing the financial balance by considering a government incentive. The principal is then:

$1,134,907.30 - $130,564.50 = $1,004,342.80

The standard mortgage equation, equation (5-65), gives the monthly payment of the loan on the initial cost, when P = $1,004,342.80, i = 4.5%/12 = 0.0045, and payment is in 10 years. Monthly payments come to $10,850.60, and the loan payment per year is

$130,200.70. The summary of each year's balance is illustrated in Figure 6-79. This chart also shows that after 7 years, the mortgage is paid off.

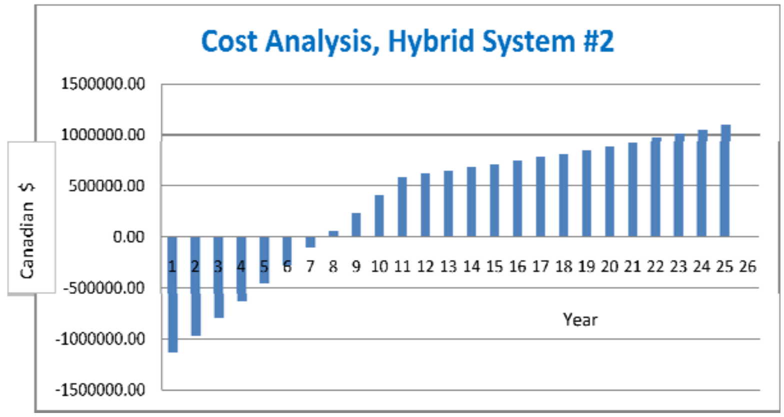


Figure 6-79, The summary of the financial balance for hybrid system #2 with government rebate for case #4

The second assumption is when there is no government rebate for purchasing renewable energy equipment. In this circumstance, the principal is the same as the product cost which is $1,134,907.30. Then, by using the standard mortgage equation, equation (5-65), the monthly payment of the loan is $12,260.57 and payment for a year is $147,126.81 for 10 years. The saving on the energy bills stays the same. All financial calculations for each year are summarized in Figure 6-80.

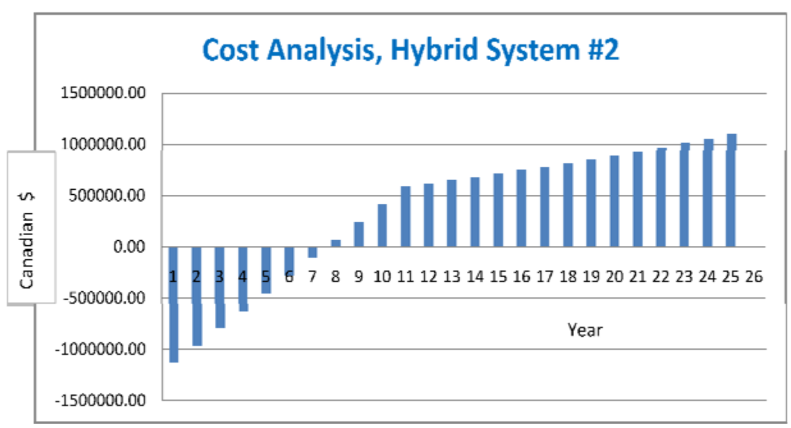


Figure 6-80, The summary of the financial balance for hybrid system #2 without the government rebate for case #4

6.6. Summary

In this chapter, four different case studies under the main category of residential, commercial, and industrial are assessed. Different options of renewable energy technology are sized for each case. Calculations are not just based on available technology - positive environmental effects of each technology are measured as well. The main factor for each decision is cost; each technology is valued from a financial point of view. All tools for making informed decisions about natural energy resources are now available. Discussion on the results of each case is from different points of view in the next chapter.

Chapter 7: Results & Discussion

7.1. Introduction

In Chapter 6, four different cases are studied and sized for different renewable technologies including solar water heaters, PV modules, ground source heat pumps and different combinations of these technologies. These cases are from residential, commercial and industrial sectors. In this chapter, data results from the previous chapter are analysed based on technological view, environmental aspects, and budget. Meanwhile, from the point of energy conservation, recommendations for each case are suggested because ultimately, saving energy is cheaper than generating energy.

7.2. Technologies Comparison

Since all the cases are in urban areas, the most available and safe renewable technologies are chosen. These technologies are solar heater collectors, photovoltaic panels, and ground source heat pumps. Hybrid systems as a combination of two technologies are designed as well. For all cases, hybrid system #1 as a combination of geothermal technology and PV panels, hybrid system #2 as a combination of solar water heaters and PV modules, and hybrid system #3 as a combination of solar water heaters and ground source heat pump are obtained. Table 7-1 briefly depicts options of renewable technologies for each case study.

Table 7-1, Technology Summaries for Four Case Studies

		Residential		Commercial	Industrial
		Case #1	*Case #2*	*Case #3*	*Case #4*
Technology	***Solar Heater Panels***	4 WSE58	4 WSE58	58 WSE58	75 WSE58
	PV Panels	22 x 215 W	56 x 210 W	100 x 215 W	650 x 215 W
	Geothermal system	GT049	GT050	n/a	n/a
	Hybrid System #1	GT049 + 8 x 210 W	GT049 + 8 x 210 W	n/a	n/a
	Hybrid System #2	4 WSE58+22 x 215 W	4 WSE58+56 x 210 W	58 WSE58+100 x 215 W	75 WSE58+650 x 215 W
	Hybrid System #3	45 WSE58+GT049	45 WSE58+GT049	n/a	n/a

Along with prioritizing different energy options, the following facts are considered as well:

- it is clear in Table 7-1 that the numbers of solar water heaters are much less for each case; the installation is cheaper for solar water heaters compared to PV panels;
- as the quantity of solar panels is larger, the space for the installation needs to be bigger;
- PV panels need to be tilted four times per year and must be cleaned after each snow, therefore PV panels require more maintenance; and
- a geothermal system is the most reliable energy system, with special initial installation and low maintenance.

7.2.1. Case #1 Technology Comparison

Case #1 is the house with low energy consumption, and six different options of renewable sources of energy. Discussion about technologies for this case is based on two categories, solar energy technologies and geothermal energy.

7.2.1.1. Solar Energy Technology Comparison

Using solar heater panels is a good choice for heating domestic hot water in this residential building because they are easy to install and maintain. However, PV panels are a good source of electricity for case #1. Using both technologies, hybrid system #2, will bring more savings to the household. As this house is in an urban neighbourhood, it would be a better idea if a subdivision as a community runs sets of PV panels; in this way, maintenance is less of a burden on individuals. Furthermore, PV panels will have a designated area which is safe from any theft or damage by children’s balls.

7.2.1.2. Geothermal Energy and Solar Energy Comparison

When comparing geothermal energy and solar energy, ground source heat pumps are in first place, since they are a reliable source of energy and incredibly cost effective. For using solar technologies, either PV modules or evacuated heat pipes, there must be a backup system in place. The main approach for solar technologies is to store energy when the sun is available, and to use the energy when it is needed. Ground source heat pumps, on the other hand, provide energy continually without interruption, and geothermal energy is always available. Moreover, the space which geothermal units needs does not change the exterior of the building, and the geothermal system is very easy to maintain. However, the initial installation of the pipes in the ground is not a clean procedure.

7.2.1.3. Alternative Energy Options Comparison

Six systems defined as alternative sources of energy are used in case #1: solar water heaters' technology to run the hot water of the household, PV modules to generate the electricity of the household, a geothermal system to run the heating and cooling system of the household, and finally different hybrid systems. Figure 6-2 shows the energy consumption distribution in case#1.

- In first place is PV modules which generate electricity for case #1. These panels are easy to install and can run any application with available electricity. The energy consumption reduction goal for this system is 100%.

- Hybrid system#3 (geothermal system + solar thermal) is the second choice from a technical aspect, since it is reliable to heat/cool space as well as providing domestic hot water in case #1. Besides, hybrid system #1 has a targeted reduction of energy consumption of the household of about 62.8% (1/5 X 56% by heating/cooling + 18% hot water).

- Hybrid system #1 (geothermal system + solar electricity) is the third choice by targeting 56% of energy consumption reduction through providing heating/cooling energy. In this fairly independent system, ground source heat pumps receive electricity by PV modules.

- Geothermal technology places fourth because this technology is dependable and cost effective as a HVAC system. Target energy reduction for this system is 44.8% (4/5 X 56%).

- Hybrid system #2 (Solar Thermal + Solar Electricity) stands in fifth place by aiming 44% energy reduction through providing domestic hot water and electricity.

The last but not the least is for solar water heaters, which provide the hot water for the household. This system is very efficient and easy to maintain. Energy reduction target for this system is 18%. Figure 7-1 depicts the summary of technology prioritization for case study #1 as follow:

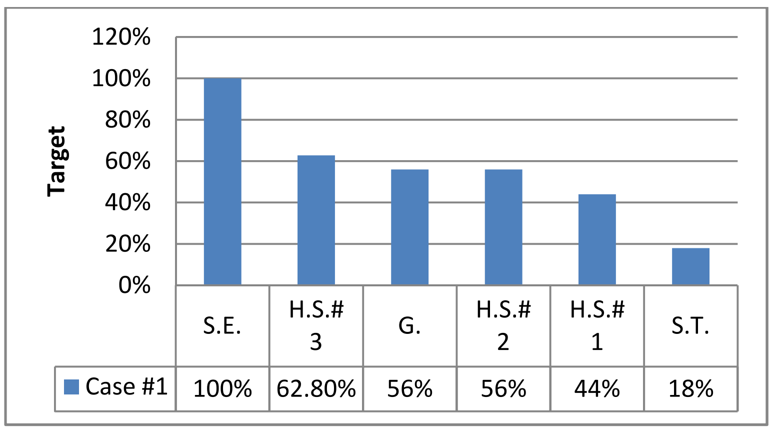


Figure 7-1, Prioritized options from technological point of view for case #1

7.2.2. Case #2 Technology Comparison

Case #2 is the house with high energy usage. The energy consumption in case #2 is almost twice that of case #1. It is strongly recommended that this household, prior to starting any renewable energy project, start changing its energy consumption pattern. By cutting the extra energy usage, the demand for PV panels will be smaller, thereby shrinking the cost.

As distribution of energy consumption is almost the same as in case #1 (Figure 6-2 is applicable to case #2), and renewable energy technologies applicable to case #2 are very similar to case #1, the technology discussion in section 7.2.1 is applicable for case #2 as well. Figure 7-2 depicts the summary of technology prioritization for case study #2 as follow:

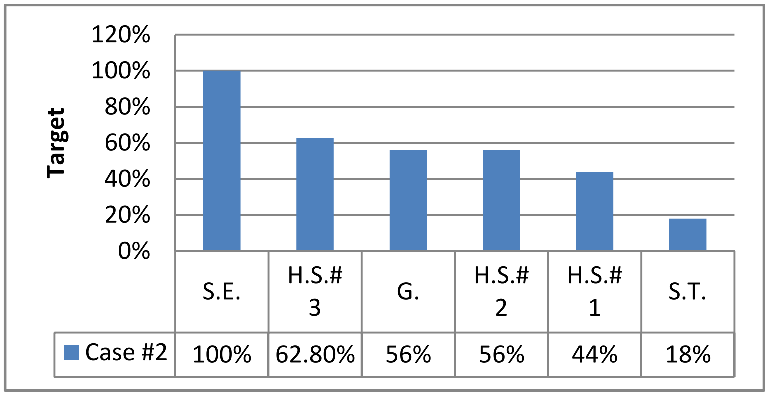


Figure 7-2, Prioritized options from technological point of view for case #2

7.2.3. Case #3 Technology Comparison

Since case #3 is a public library, it is a reasonable decision to run the library partially with renewable energy. This action not only reduces energy bills, but also encourages people to be friendlier towards solar energy and renewable energy. Solar energy in this case works as a slogan as well as technology to convert solar energy to a domestic energy.

Six systems are defined for case #3. Three of them are designed in greater detail and rest systems could not be calculated because of lack of information. These systems are prioritized by using energy consumption distribution in the library (Figure 6-44) as follows:

- Hybrid system #2 (Solar Thermal + Solar Electricity) is in first place. Solar thermal energy tackles 57% of the space heating energy consumption and PV modules aim for 47% electricity consumption. Achieving these percentages depends on sunny hours per day.
- Evacuated pipes stand in second place by targeting 57% reduction of energy consumption for heating the space.
- PV modules are in third place with a maximum target of 47% reduction of energy consumption. Figure 7-3 shows the summary of technology prioritization for case study #3 as follow:

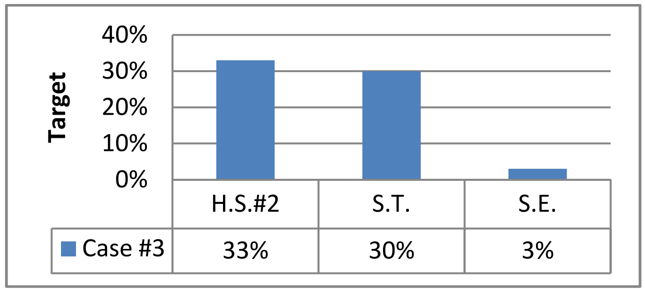


Figure 7-3, Prioritized options from technological point of view for case #3

In order to boost the efficiency in this commercial building, the following improvements should be applied:

I. Lights

Using LED lights in hallways, offices and reading areas is recommended to reduce electricity consumption. Also, turning off the lights when library is closed saves a good amount of electricity.

LED lights are a new technology in lighting field. These lights are recommended because:

- LED lights last more than 50,000 hours compared to 8,000 hours for compact fluorescents and 1,000 hours for incandescent lights, and are very durable;
- LED lights use 1/10th electricity compared to incandescent lights, though they are very energy efficient; and
- LED lights generate light but do not create as much heat, therefore no burning can happen with LED lights as they run with cool temperatures.

II. Computers

Shut down all computers when the library is closed. This change is at no cost.

III. Heating/Cooling

Set the programmable thermostat at 20°C instead of 22°C in the winter. Also, set the temperature on 16°C during nights and when the library is closed.

For the summer time, set the thermostat at 24°C during open hours and shut down the air-conditioner when the library is closed.

Reduce the hot water temperature to 55°C instead of 60°C all year round.

7.2.4. Case #4 Technology Comparison

For case #4, the plastic injection company as an industrial building example, six systems for providing renewable energy are defined in Chapter 6. Three systems are calculated completely as information is available for calculations. Figure 6-65 (energy consumption distribution) is the main tool for prioritizing the calculated technologies.

- Hybrid system #2 (Solar Thermal + Solar Electricity) stands in first place. Solar thermal tackles 24% space heating energy consumption and PV modules aimed for 76% electricity consumption. Achieving these percentages depends on sunny hours per day.
- PV modules are in third place by a maximum target of 76% reduction of energy consumption.
- Evacuated pipes stand in second place by targeting a 24% reduction of energy consumption for heating the space.

Figure 7-4 illustrates the summary of technology prioritization for case study #4 as follow:

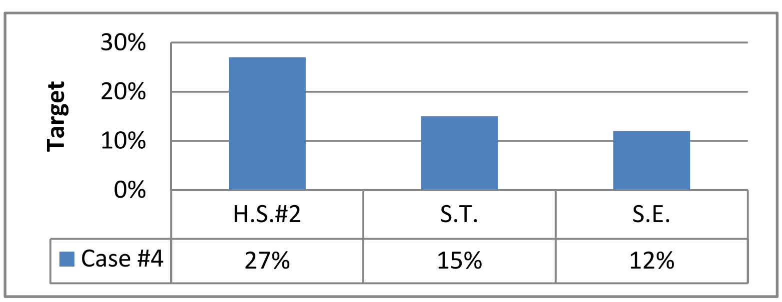


Figure 7-4, Prioritized options from technological point of view for case #4

Besides energy consumption reduction, some other factors should be considered, factors which are related completely to the nature of case #4. Solar collectors heat the space and water, are easy to install and are low in maintenance. Photovoltaic panels are a practical solution to reduce or increase the electricity grid load. For the injection company, maintenance is less of an issue because as a technical operations company, there are maintenance people who can be in charge of the PV panels' maintenance. Considering the huge amount of electricity needed to run their operation, they must get help from the sun, even partially is a reasonable idea to reduce the hydro's load. However, using both technologies is the best option for the company.

Parallel to providing a clean source of energy for the plastic injection company, efficiency should be increased. Using energy effectively is less costly than generating energy. In an industrial building, efficiency can be improved in different departments:

I. Lighting

Usually second shifts are only working on the floor and most of the offices are vacant, but lights are on. Using sensors in the offices and hallways allows employees to use lights when they need to in the afternoon.

Moreover, replacing regular lights with LED lights in hallways, office spaces and floor areas is strongly recommended.

II. Computers

All twenty computers are always on even though they are only used 45 hours per week. Set a new policy to turn of the computers when not in use. This change has no cost for the injection company and saves electricity.

III. Heating

To reduce the heat load, the hot water temperature can be set to 55°C instead of the regular 60°C. In the same way, office temperature can be set to 20°C instead of 22°C. Set the temperature during the evening and the weekend on 15°C. These changes are also at no cost to the injection company.

Management can also consider a budget to add industrial curtains to four docks to prevent energy loss while loading.

IV. Motors

Usually all motors have a 75% load factor. By upgrading motors to premium efficiency units at a cost of about $1,000 per motor, efficiency of motors will be increased.

7.3. Environmental Comparison

The detailed calculation for solar heater panels, PV panels, and geothermal technology and hybrid systems for each of the four cases has been done in the previous chapter. The positive effect of each technology on the environment by preventing emission in CO_2 has been calculated. The environmental supportive effects of each technology for each case is summarised in Table 7-2.

Table 7-2, Environmental Effect Summaries for Four Cases

		Residential		Commercial	Industrial
		Case #1	*Case #2*	*Case #3*	*Case #4*
Environment	*Solar Heater Panels*	1161 kg CO2	1161 kg CO2	70652 kg CO2	21700 kg CO2
	PV Panels	1581 kg CO2	3892 kg CO2	7312 kg CO2	47391 kg CO2
	Geothermal sys.	3150 kg CO2	3150 kg CO2	n/a	n/a
	Hybrid System #1	3466 kg CO2	3466 kg CO2	n/a	n/a
	Hybrid System #2	2741 kg CO2	5053 kg CO2	23800 kg CO2	69100 kg CO2
	Hybrid System #3	4311 kg CO2	43121 kg CO2	n/a	n/a

Table 7-2 shows the effect of different technologies on eliminating CO_2 for each case study. However, for each case study, more than one project can be run. For example, for case #2, solar water heaters and PV panels can be installed without any interference. By using both technologies, CO_2 would be reduced drastically; however, if prioritizing the technologies is the case, then overall from Table 7-2, PV panels protect the environment slightly more than solar water collectors. And even geothermal is a better protector from the environment. By using two technologies, hybrid systems maximize the environmental guard.

7.3.1. Case #1 Environmental Comparison

In this residential house, hybrid system #3 (Solar Thermal & Geothermal) reduces the maximum CO_2 emissions by 4311 CO_2/year. Hybrid system #1 protects the environment by 3466 kg CO_2/year, so this design, which is a combination of geothermal technology and PV modules, stands in second place. Third place is for geothermal technology with a reduction of 3150 kg CO_2/year. Hybrid system #2 by a reduction of 2741 CO_2/year is in fourth place. PV modules, with protection of 1582 CO_2/year, stand in fifth place. By using four solar heater panels, the environment is protected by 1,161 kg CO_2/year. Evacuated tubes are the last choice. Figure 7-5 illustrates the summary of environmental protection prioritization for case study #1 as follow:

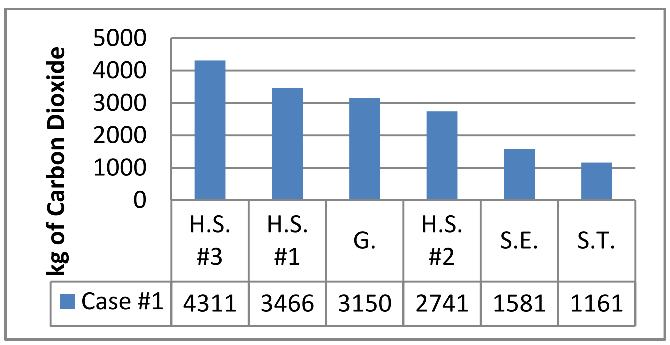


Figure 7-5, Prioritized options from environmental point of view for case #1

7.3.2. Case #2 Environmental Comparison

In case #2, the residential house with high energy consumption, for prioritizing renewable energy technologies from the point of environmental protection, hybrid system #2 (Solar Thermal & PV modules) with 5053 CO_2/year would be the first choice. Second place is reserved for hybrid system #3 (Solar Thermal & geothermal) by protecting the environment by 4311 CO_2/year. Hybrid system #1 (Geothermal & PV modules) is the third choice of technology by saving nature from 3466 CO_2/year. Fourth choice is PV modules - using 56 photovoltaic panels, the environment will be protected from 3,892 kg

CO_2/year. Ground source heat pumps stand in fifth place by 3150 CO_2/year. The last choice would be evacuated pipes which save the environment from 1,161 kg CO_2/year, by using four solar collector panels. However, as suggested, by making some changes around the house to increase energy efficiency, the environment will also be protected by reducing energy consumption. Figure 7-6 depicts the summary of environmental protection prioritization for case study #2 as follow:

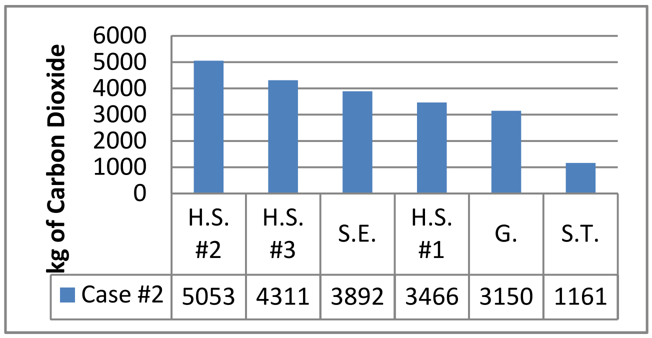


Figure 7-6, Prioritized options from environmental point of view for case #2

7.3.3. Case #3 Environmental Comparison

Case #3, the central Brampton library, can save the environment 23800 CO_2/year by using hybrid system #2. As the second choice, solar thermal pipes save the environment by using 58 solar collector panels to heat the space and water by 70,652 kg CO_2/year. As a third option, using 100 PV panels protects nature from 7,312 kg CO_2/year. Replacing renewable energy technology, using the energy effectively is strongly recommended. The customised tips to save energy for case #3, is mentioned in section 7.3.2. By reducing energy consumption, the environment instantly gets protection against CO_2. Figure 7-7 shows the summary of environmental protection prioritization for case study #3 as follow:

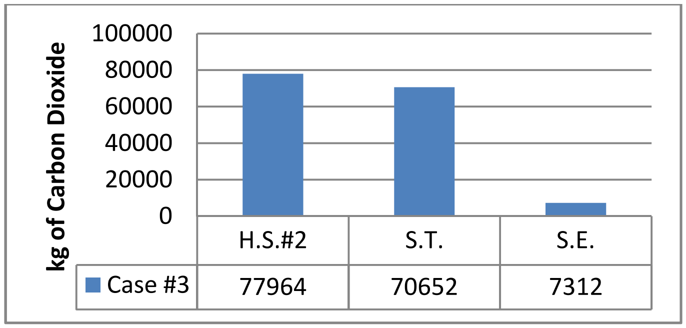


Figure 7-7, Prioritized options from environmental point of view for case #3

7.3.4. Case #4 Environmental Comparison

Case #4 is a plastic injection company which uses huge amounts of energy to run the production machines, heating the offices and production area. The first option of renewable energy technology with maximum environmental protection is hybrid system #2 (Solar Thermal and PV modules) with 96100 CO_2/year. The second technology is PV modules, where applying 650 photovoltaic panels generates portions of needed electricity to the company while saving the earth from 47,391 kg CO_2/year. The last choice is solar thermal, using 75 solar water collectors to heat the space and water; the environment will be protected from 21,700 kg CO_2/year. Figure 7-8 illustrates the summary of environmental protection prioritization for case study #4 as follow:

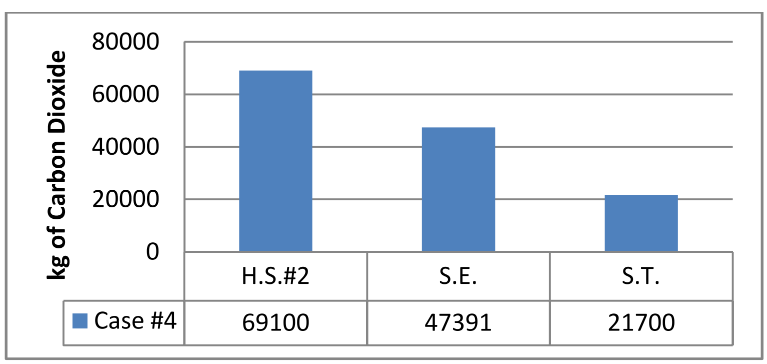


Figure 7-8, Prioritized options from environmental point of view for case #4

Meanwhile, following the recommended tips to save energy is another effective and instant way to save the environment from over use of energy.

7.4. Cost Comparison

Cost is one of the main aspects for making decisions on running any project. In Chapter 6, costs are calculated for all cases with two assumptions when there is incentive by government and when there is no incentive (no rebate). The cost of each project and related governmental subsidies are summarised in Table 7-3. In this table, costs of the projects can easily be compared for each case study. It should be noted that the prioritization in this section is based simply on the cost; performance has no ruling on this prioritization.

Table 7-3, Cost Summaries for Four Cases

		Residential		Commercial	Industrial
		Case #1	*Case #2*	*Case #3*	*Case #4*
Cost/Rebate	***Solar Heater Panels***	$4956 / $644	$4952 / $644	$70652 / $8129	$91361 / $10511
	PV Panels	$39245 / $511	$97556 / $11223	$169470 / $19496	$1043547 / $120054
	Geothermal sys.	$36160 / $9879	$36160 / $9879	n/a	n/a
	Hybrid System #1	$48493 / $11499	$48493 / $11499	n/a	n/a
	Hybrid System #2	$44196 / $13326	$103507 / $13326	$240117 / $27624	$1134970 / $130564
	Hybrid System #3	$41111 / $10523	$41111 / $10523	n/a	n/a

Table 7-3 illustrates a huge difference between the cost of solar heater projects and PV module projects in each case. As previously mentioned, both cases can be run simultaneously, however, if budget is an issue, solar heater panels are less expensive to buy, to install, and to run. Although the first choice would be solar water collectors and PV panels would be the second choice, geothermal is in third place and hybrid systems are in last place. By referring to more details in Chapter 6, all initial investments will be returned in time by saving on energy bills. In the following paragraphs, each vase study is discussed from an individual cost point of view.

7.4.1. Case #1 Cost Comparison

If making the decision by cost alone, first place goes to solar water panels with the lowest cost of $4,956. The return on investment is less than five years. Geothermal technology stands in second place at a cost of $36,160, with a return of investment in less than eight years. Third place is for PV modules at a cost of $39,245. Photovoltaic panels have higher costs, but have better savings on energy bills, and in approximately eight years the initial investment is returned by the amount of savings. Hybrid system #3 (Geothermal and Solar Thermal) with a cost of $41,111 are the fourth choice for renewable technology for case #1; return of investment for this system is five years. The fifth place is for hybrid system #2 (Solar Thermal and PV modules) with a cost of $44,196 and a return of investment in six years. Hybrid system #1 (Geothermal and PV modules), stands in last place with a cost of $48,493 and a return of investment in less than eight years. Figure 7-9 depicts the summary of cost prioritization for case study #1 as follow:

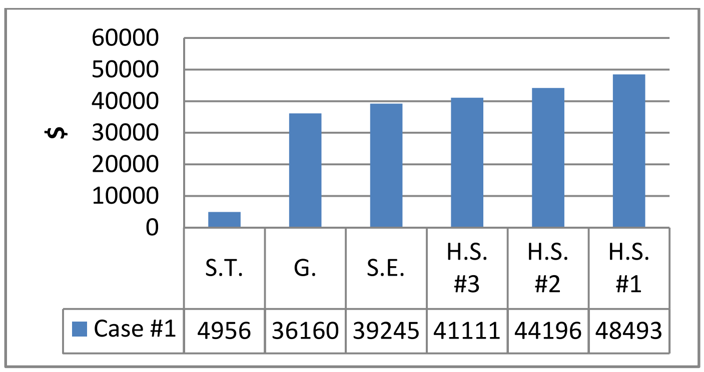


Figure 7-9, Prioritized options from financial point of view, case #1

7.4.2. Case #2 Cost Comparison

Choosing the right technology from the budget point of view, votes go to solar collector panels as these panels are expensive and the return on investment is faster in comparison to photovoltaic panels. This is the residential house with high energy consumption.

In case #2, the first economical choice is the solar water heaters project with a cost of $4,952 and a return on investment in four years. Geothermal technology stands in second place at a cost of $36,160 and a return on investment in less than eight years. Hybrid system #1 (Geothermal and PV modules), stands in third place with a cost of $48,493 and a return on investment in less than eight years. Hybrid system #3 (Geothermal and Solar Thermal) with cost of $41,111 is the fourth choice for renewable technology for case #1, with a return on investment for this system being five years. The fifth choice is PV modules with a cost of $97,556 and a return of investment in seven years. And last but not least, the choice of technology is hybrid system #2 at a cost of $103,507 and a return on investment is in eight years.

In comparing the cost of PV panels for case #2 with case #1, which is a residential house with moderate energy consumption, the dollar value of saving energy in renewable technology shows up. As displayed in Table 7-3, the initial cost for running case #1 is less than half of that for case #2 with its high energy consumption pattern. This is the practical proof for the value of saving energy in the first place. It is much cheaper and easier. Figure 7-10 depicts the summary of cost prioritization for case study #2 as follow:

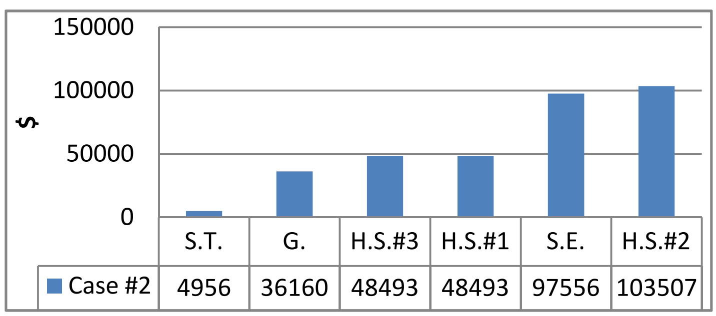


Figure 7-10, Prioritized options from financial point of view, case #2

7.4.3. Case #3 Cost Comparison

For case #3, the Brampton central library, the budget comes from taxpayers through the municipal government. Spending money is not just for buying the technology; this budget partially increases the public's knowledge of the subject of renewable energy. For this case, using solar panels is strongly recommended as the first choice, because solar heater panels for this case can be run with less than half the price of the PV modules project; moreover, solar heaters protect the environment more than PV panels in this case. Solar heater panels will pay for themselves in less than 3 years through savings in natural gas bills. Solar thermal can be run at a cost of $70,652. The second choice is using PV panels to generate partial electricity for the library at a cost of $169,470 and a return of investment in seven years. The last choice of renewable technology is hybrid system #2 (Solar Thermal and PV modules) with a cost of $240,117 and a return of investment in seven years. Figure 7-11 shows the summary of cost prioritization for case study #3 as follow:

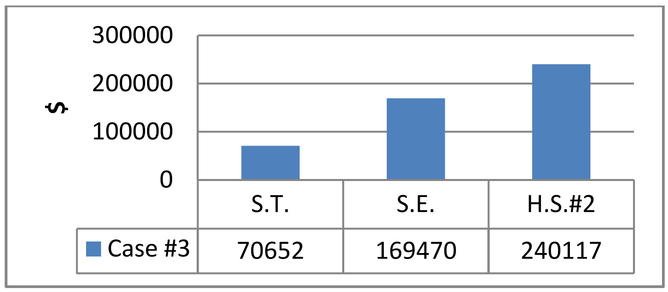


Figure 7-11, Prioritized options from financial point of view, case #3

Running any of these solar energy projects uses energy effectively and creates instant savings for the library (section 7.2.3).

7.4.4. Case #4 Cost Comparison

For case #4, which is a plastic injection company, by comparing the costs of solar heater panels and PV panels in Table 7-3, it is obvious that solar water heaters are more reasonable. The cost of solar water heaters is one-tenth that of PV panels ($91,361). The return on investment on solar heater panels is five years, while the return on investment for PV panels is eight years, and the initial cost of a PV module project is $1,043,597. Running the solar water heaters initially costs less; however, savings through PV panels is much higher. During the 25 year life of the project, PV panels create six times more savings than solar water heaters. Finally, if management is considering long term goals for the company, it should consider PV panels as well. The last economical renewable energy technology for case #4 is hybrid system #2 (Solar Thermal and PV modules) at a cost of

$1,134,970 with seven years return on investment. Figure 7-12 depicts the summary of cost prioritization for case study #4 as follow:

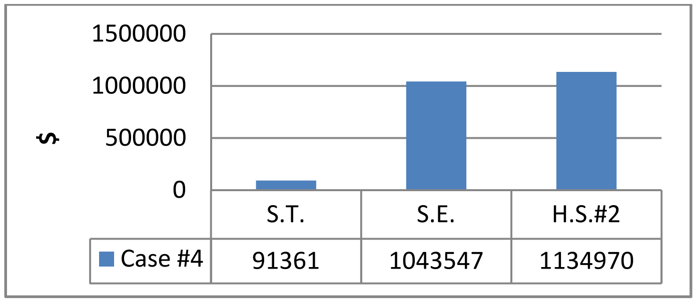


Figure 7-12, Prioritized options from financial point of view, case #4

Meanwhile, following tips in section 7.2.4 makes immediate savings for the company by using energy effectively.

7.5. Summary

Table 7-4 depicts the summarization of all cases from a technological point of view, environmental impact, and price tag. By checking all aspects, using both solar technologies has the greatest positive effect on the environment. However, when there is some limitation on the budget, choosing the solar water heater panels is the optimum choice.

The initial cost for solar panels is less than the initial cost of PV modules; installation, space and maintenance for PV panels are higher than solar heater panels. However, in the long run, PV panels create more savings on energy bills. PV panels protect the environment from CO_2 more than solar heater panels in all four cases; however, PV panels are more expensive.

The geothermal system is a reliable technology which protects the environment the most; however, the initial installation is costly. Hybrid systems, taking advantage of two different renewable technologies, protect the environment better but need more funds to establish.

Table 7-4, Summaries for Four Case Studies

		Residential		Commercial	Industrial
		Case #1	Case #2	Case #3	Case #4
Technology	Solar Heater Panels	4 WSE58	4 WSE58	58 WSE58	75 WSE58
	PV Panels	22 x 215 W	56 x 210 W	100 x 215 W	650 x 215 W
	Geothermal sys.	GT049	GT050	n/a	n/a
	Hybrid System #1	GT049 + 8 x 210 W	GT049 + 8 x 210 W	n/a	n/a
	Hybrid System #2	4 WSE58+22 x 215 W	4 WSE58+56 x 210 W	58 WSE58+100 x 215 W	75 WSE58+650 x 215 W
	Hybrid System #3	45 WSE58+GT049	45 WSE58+GT049	n/a	n/a
Environment	Solar Heater Panels	1161 kg CO2	1161 kg CO2	70652 kg CO2	21700 kg CO2
	PV Panels	1581 kg CO2	3892 kg CO2	7312 kg CO2	47391 kg CO2
	Geothermal sys.	3150 kg CO2	3150 kg CO2	n/a	n/a
	Hybrid System #1	3466 kg CO2	3466 kg CO2	n/a	n/a
	Hybrid System #2	2741 kg CO2	5053 kg CO2	23800 kg CO2	69100 kg CO2
	Hybrid System #3	4311 kg CO2	43121 kg CO2	n/a	n/a
Cost/Rebate	Solar Heater Panels	\$4956 / \$644	\$4952 / \$644	\$70652 / \$8129	\$91361 / \$10511
	PV Panels	\$39245 / \$511	\$97556 / \$11223	\$169470 / \$19496	\$1043547 / \$120054
	Geothermal sys.	\$36160 / \$9879	\$36160 / \$9879	n/a	n/a
	Hybrid System #1	\$48493 / \$11499	\$48493 / \$11499	n/a	n/a
	Hybrid System #2	\$44196 / \$13326	\$103507 / \$13326	\$240117 / \$27624	\$1134970 / \$130564
	Hybrid System #3	\$41111 / \$10523	\$41111 / \$10523	n/a	n/a

The final decision absolutely depends on owners or management's budget and mentality in each case. However, using energy smartly and eliminating energy waste is always recommended. This is instant money saving and protecting the environment from harmful emissions.

Chapter 8: Conclusion and Recommendation for Future Research

8.1. Conclusion

Results show that if a target is reducing CO_2 emissions, hybrid systems are the best. In contrast, when decision making is based on budget, solar water tubes are the first choice and hybrid systems are the last choice. Prioritizing based on technology does not follow a pattern for all three types of buildings - because the nature of energy consumption is diverse, it depends on the type of building.

Not only the technology, environmental protection and cost are the main parameters for deciding on renewable technologies, but also are the reliability, installation, maintenance and ease of use. The final conclusion follows:

- Solar thermal technology is an efficient technology for heating space and domestic hot water, with the lowest initial cost, easy for installation, and low in maintenance.
- Photovoltaic modules are a practical technology to provide electricity, and also high in maintenance.
- Ground source heat pump is a reliable renewable technology, with the highest possible efficiency, and complicated installation.
- Hybrid Systems are holding advantages of 2 renewable technology systems, whole they are very costly.

8.2. Recommendation for Future Research

No doubt many studies must be conducted to make renewable energy, and especially solar energy, more accessible to protect human's future. There is much room for work on renewable energy to make it friendly and easy to use, like the conventional electricity grid. For example, one project in continuation of this thesis could be designing a proper location in a residential area for installation of PV panels and planning related details, like a maintenance program, protection plan, and distribution plan. Using PV panels individually by house owners is not really practical, however, localizing a set of PV panels and distributing solar electricity would be better ideas. Another project could be localizing the heat by solar water heaters in a community and distributing the heat throughout the neighbourhood. The potential studies follow:

1. Localizing and distributing clean energy for photovoltaic modules and wind turbine.
2. Localizing and distributing for hot water and hot air.
3. Planning for distributing plan, maintenance program, and protection plan, distributing plan.

References

Akbari, H., Sezgen, O., 1992 Analysis of energy use in building services of the industrial sector in California: two case studies, Energy and Building 19, 133-141.

Alert idea's website, 2009 www.alertidea.com

Al-Ghandoor, A., Al-Hinti, I., Jaber, J.O., Mansour, I.M., 2008 Residential past and future energy consumption: Potential Saving and environmental impact, Renewable & Sustainable Energy Reviews.

American Society of Heating, Refrigeration, and Air-conditioning Engineers, Inc. (ASHRAE), 1995 Handbook of applications, Atlanta, GA: ASHRAE: [Chapter 29].

Anon. Global energy perspective to 2050 and beyond, 1995 Technical Report London: World Energy Council.

Argiriou, A., Balaris, C., Daskalaki, E., Gaglia, A., Santamouris, M., 1994 Energy characteristics and saving potential saving in office buildings, Solar Energy 52: (1) 59-66.

ASHRAE, Commercial/Institutional Ground-Source Heat Pump Engineering Manual: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1995 Atlanta, GA, USA.

ASHRAE, Handbook, Fundamentals, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1981 Atlanta, GA, USA.

ASHRAE, Handbook, Fundamentals, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1985 Atlanta, GA, USA.

Ayres, R.U., Ayres, L.W., Martinas, K., 1998 Exergy, waste accounting, and life cycle analysis, Energy 23: 355-363.

Balaris, C., Daskalaki, E., Droutsa, K., Gaglia, A., 2003 Energy conservation potential, HVAC installations and operational issues in Hellenic airports, Energy and Building 35: 1105-1120.

Ballinger, J.A., 1988 The 5 stars design rating system for thermally efficient, comfortable housing in Australia, Energy and Building 11: (1-3) 65-72.

Barbrier, E., 2002 Geothermal energy technology and current status: an overview, Renewable and Sustainable Energy Reviews; 6: 3-65.

BE2AM 2000 Building energy and environmental assessment method, Private Communication from ECD.

Belzer, D.B., Scott, M.J., Sands, R.D., 1995 Climate change impacts on US commercial building energy consumption; an analysis using sample survey data, Energy Source, 18, 177-201.

Berg, M.R., Hassett, M.L., 1984 Conservation and solar energy in residential and commercial buildings: the northern industrialized USA, Energy Policy (March) 93-101.

Bloem, J.J., Marco, J., Neirac, F.P., Richalet, V., Tellez, F., 2001 HELP (house energy labelling procedure): methodology and present results. Energy Building 33: (3) (2001).

Boland, J., Kilsby, R., Kravchuk, O., Saman, W., 2003 Estimation of thermal sensitivity of the dwelling to variations in architectural parameters, Environmental Modeling and Assessment 8: 101-113.

Bonus-Info newsletter's website, 2009 www.windmission.dk/workshop/BonusTurbine.pdf

Bows, A., Anderson, K.L., 2007 Policy clash: can projected aviation growth be reconciled with the UK government's 60% carbon reduction target? Transport Policy 14: (2), 103-110.

Bradley, R.A., Watts, E.C., Williams, E.R., 1991 Limiting net greenhouse gas emission in the United States, Washington DC: US department of energy.

BREEAM-environmental assessment for the new office designs. 1990. BRE, Garston, Watford, WD2 7JR, UK.

Burnett, J., Lee, W.L., 2008 Benchmarking energy use assessment of HK-BEAM, BREEAM and LEED, Building and Environment 43: 1882-1891.

Calla, R., DePani S., Fazio, P., Zmeureanu, R., 1999 Development an energy rating system for existing houses, Energy and Building 29: (2) 107-119.

Canadian Electricity Association's, 2009 website, www.canelect.ca

Canadian Wind Energy, 2009 Atlas www.windatals.ca

Carey, V.P., Creyts, J.C., 1997 Use of extended exergy analysis as a tool for assessment of the environment impact of industrial process, In: Ramalingam, M.L., (Ed) Proceeding of the ASME Advanced energy system division, AES-vol. 37, ASME, New York, pp. 129-137.

Cengel, Y.A., Kanoglu, M., 1999 Improving the performance of an existing binary geothermal power plant: a case study, Transactions of the ASME, Journal of Energy Resources Technology 121: (3) 196-202.

Cengel, Y.A., Kanoglu, M., 1999 Retrofitting a geothermal power plant to optimize performance: a case study, Transactions of the ASME, Journal of Energy Resources Technology 121: (4) 295-301.

Chen, J., Kaushik, S.C., Tyagi, S.K., 2005 Optimal criteria based on the ecological function of an irreversible intercooled regenerative modified Brayton cycle, International Journal of Exergy 2, 90-107.

Chen, Z., Clements-Croome, D., Hong, J., Li, H., Xu, Q., 2006 A multi Criteria lifespan energy efficient approach to intelligent building assessment, Energy and building 38: (5) 393-409.

Colonbo, U., 1992 Development and the global environment, In: Hollander J.M., editor. The Energy-Environment Connection, Washington, Island Press, p. 3-14.

Connelly, L., Koshland, C.P., 1997 Two aspects of consumption: using an exergy-based measure of degradation to advance the theory and implementation of industrial ecology, Resources, Conservation and recycling 19: 199-217.

CORE, 2004 Konzept der Engieforschung des Bundes 2004 bis 2007, (Swiss federal energy research master plan for the years 2004-2007.), Bundesamt fur engiriewirtschaft, Bern (Germany).

Cornelissen, R.L., 1997 Thermodynamic and Sustainable Development, PhD Thesis, University of Twente, The Netherlands.

Dahlsven, T., Pagerhaung, K., 1994 Energy evaluation by the key number method, Caddet Energy Efficiency Newsletter, IEA CADDET Energy efficiency, Didcot, Oxon 0X1 10QA UK 4.

Dascalaki, E., Flourentzou, F., Koronaki, I., Labban, H.H, Santomouris, M., Richalet, V., Roulet,C.A., 2002 ORME: a multi-criteria rating methodology for buildings, Building and Environment 37: (6) 579-586.

Dascalaki, E., Santomouris, M., 2002 Passive retrofitting of office buildings to improve their energy performance and indoor environment: the office project, Building and Environment 37: (6) 575-578.

Devine-Wright, P., 2005a Local aspects of UK renewable energy development: exploring public beliefs and policy implications, Local Environment 10: (1), 57-69.

Dincer I., Hussain M.M, Al-Zaharnah I., 2004 Energy and exergy utilization in transportation sector of Saudi Arabia, Applied Thermal Engineering 24: 525–538.
Dincer, I., 1998 Energy and environmental impacts: present and future perspectives. Energy Sources 20 (4/5): 427-53.

Dincer, I., 2000 Renewable energy and sustainable development: a crucial review, Renewable and Sustainable Energy Reviews 4: 157-175.

Dincer, I., Hepbasli, A., Ozgener, L., 2005 Energy and exergy analysis of geothermal district heating systems: an application, Building and Environment 40: 1309-1322.

Dincer, I., Kanoglu, M., Rosen M.A., 2008 Role of exergy in increasing efficiency and sustainability and reducing environmental impact, Energy Policy; 36: 128-37.

Dincer, I., Midilli, A., 2007 Key Strategies of hydrogen energy systems for sustainability, International Journal of Hydrogen Energy 32(d): 511-24.

Dincer, I., Midilli, A., 2008 Hydrogen as a renewable and sustainable solution in reducing global fossil fuel consumption, International Journal of Hydrogen Energy 33: 4209-4222.

Dincer, I., Rosen M.A., 2003 Thermodynamic analysis of power plants: an application to a coal-fired electrical generating station, Energy Conversion and Management 44: 2743-2761.

Dincer, I., Rosen M.A., 2005 Thermodynamics aspects of renewable and sustainable development, Renewable and Sustainable Energy Reviews 9 (2): 169-89.

Donald, a., 1998 Putting it together: whole building and a whole building policy, Renewable Energy Policy (5) (1998).

Doukas, P., Gaitani, N., Geos, V., Santomouris, M., Sfakianaki, M., Mihalakakou, G., Papaglastra, M., Patargias, P., Pavlou, C., Primikiri, E., 2007 Using intelligent clustering techniques to classify the energy performance of school building, Energy and Buildings 39: (1) 45-51.

Eco totally life's website, 2009 www.ecotality.com

Edgerton, R.H., 1992 Available energy and environmental economics, D.C. Health Toronto.

ETH-Rat, 1998 2000Watt-Gsellschaft-Modell Schweiz, Strategie Nachhaltigkeit im ETH-Beriech, Wirtschaftsplattorm, (2000 Watt-Society-Switzerland as a model). ETH-Rat, Zurich (Germany)

Ewing, Rex A., 2003 "Power with nature".

Favre, P , Trachsel, Ch., 1981 La signature energy etique. LESO report, Lausanne; Favre, P., Weinmann, Ch., Barde, O., Trachsel, Ch., La signature energy etique-outil du diagnostic thermique du batiment, Annales de 1"ITBTP No. 1983, 419: 58.

Fazio, P., Zmeureanu, R., 1992 Analysis of the energy performance of office building in Montreal 1998 Energy and Building; 17: 63-74.

Fels, M.E., 1986 The Princeton scorekeeping method (PRISM), Energy and Buildings, 9: 1.

Fung, A.S., Ugursal, V.I., 1988 Residential carbon dioxide emission in Canada: impact of efficiency improvements and fuel substitution global environmental change, Volume 8, Issue 3, 263-273.

Gaggioli, R.A., Wepfer, W.J., 1980 Reference datum for available energy, In: Gaggioli, R.A., (Ed.), Thermodynamics: Second law analysis, ACS Symposium Series 122, Washington, DC, 77-92.

Gaterell, M.R., McEvoy, M.E., 2005 The impact of climate change uncertainties on the performance of energy efficiency measures applied to dwellings, Energy and Building 37, 982-995.

GEO. Geothermal Energy Facts, 2004 Geothermal education office, California, USA (http://geothermal.marin.org/pwrheat.html#Q1).

Geosmart Energy website, 2009 www.geosmartenergy.com

Giddings, B., Underwood, C., 2007 Renewable energy in remote communities, Journal of Environmental Planning and Management 50: (3), 397-419.

Government Newspaper, 1998 Issue 2147504704, August 19th

Granada, E., Lopez-Gonzalez, L.M., Miguez, J.L., Moran, J.C., Murillo, S., Vicuna, J.E., Porterio, J., 2006 Review of the rating of dwelling in the European Union as a mechanism for sustainable energy, Renewable and Sustainable Energy Reviews 10: (1) 24-45.

Granovskii, M., Dincer, I., Rosen M.A., 2007 Exergetic life cycle assessment of hydrogen production from renewable, Journal of Power Sources: 167: 461-71.

Hartly, D.L., 1990 Perspectives on renewable energy and the environment, In: Tester, J.W., Wood, D.O., Ferrari, N.A., editors. Energy and the Environment in the 21st century, Massachusetts: MIT.

Heidari, S., Sharples, S., 2002 A comparative analysis of short-term and long-term thermal comfort surveys in Iran, Energy and Building 34: 607-614.

Hinnells, M., 2008 Combined heat and power in industry and buildings, Energy Policy 36 (2008) 4522-4526.

Hodder, S.G., Loveday, D.L., Parsons, K.C., Taki, A.H., 2002 Displacement ventilation environments with chilled ceiling: thermal comfort design with the context of the BS EN ISO 7730 versus adaptive debate, Energy and Buildings 34: 573-579.

Honnery, D., Moriarty, P., 2008 Mitigating greenhouse: Limited time, limited options, Energy Policy 36: 1251-1256.

Horie, Y.A., Keoleian, G.A., Kim, H.C., 2006 Optimal household refrigerator replacement for life cycle energy greenhouse gas emission s and cost, Energy Policy 34: 2310-2323.

Hydro-Québec, 1994 Projet ÉVAL ISO : Rapport final sur le potentiel d'amélioration del'enveloppe thermique des habitations du Québec, Vice-présidence, Effi cacité énergétique, Service Conception de programmes - Marché résidentiel, July.

IGSHPA, 1998 Closed-Loop/Ground Source Heat Pump Systems Installation Guide, International Ground-source Heat Pump Association, Oklahoma State University, Stillwater, Oklahoma, USA.

Imboden, D., Kost, M., Siller, T., 2007 Long-term energy savings and greenhouse gas emission reductions in the Swiss residential sector, Energy Policy, 35: 529-539.

Imboden, D., Roggo, C., 2000 Die 2000 Watt-Gsellschaft: Der Mondflung des 21. Jahrhunderts. (The 2000 Watt-Society: The landing on the moon in the 21st century.) ETH Bulletin 276, Zurich (Germany)

IPCC, 2001 Climate change 2001: The scientific Basis, Cambridge University Press, Cambridge.

Jochem, E., (ED), 2004 Steps towards a sustainable development, A white Book for R&D of Energy-Efficient Technologies, CEPE/ETH Zurich and Novatlantis, Zurich.

Kanoglu, M., 2002 Exergy analysis of a dual-level binary geothermal power plant. Geothermics; 31: 709-24.

Kavalari, F., 2001 Heating-Air conditioning – Saving Energy – Intelligent Buildings, Weekly Bulletin of the Technical of Greece 2172 (October 29th).

Kavanaugh, P.K. and Rafferty, K., 1997 Ground-source Heat Pumps – Design of Geothermal Systems For Commercial and Institutional Buildings, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA, USA.

Kellete, J., 2007 Community-based energy policy: a practical approach to carbon reduction. Journal of Environmental Planning and Management 50: (3), 381-396.

Kemp, William H., 2005 “Renewable Energy Handbook”

King, S., Kordjamshidi, M., 2009 Overcoming problems in house energy rating in temperate climate: A proposed new rating framework, Energy and Building 41: 125-132.

Koomey, J.G., Mahler, S.A., McMahon, J.E., Webber, C.A., 1999 Projected regional impacts of appliance efficiency standards for the US residential sector, Energy Policy 24: 69-84.

Kotas, T.J., 1995 The exergy method of thermal plant analysis, Reprinted, Krieger, Malabar, F.L.

Kyristsis, D.C., Rakopoulos, C.D., 2006 Hydrogen enrichment effects on the second law analysis of natural and landfill gas combustion in engine cylinders, International Journal of Hydrogen Energy; 31: 1384-93.

Letcher, M., Redgrove, Z., Roberts, S., Longstaff, B., Inverarity, A., 2007 Mobilising individual behaviour change through community initiatives: lessons for climate. Report by the centre for sustainable energy (CSE) and community development exchange (CDX) for: DEFRA, communities and local government, DTI, DfT and HM Treasury, Available from http://www.cse.org.uk/pdf/pub 1073.pdf

Levermore, G. Chow, D.H., 2004 Climate change assessment and building performance, In: CIB world building congress 2004.

Lin, B., Xia, C., Xia, C., 2008 Renewable energy utilization evaluation method in green buildings, Renewable Energy, 33: 883-886.

Markis, T., Paravantis, J.A., 2007 Energy conservation in small enterprises, Energy and Building, 39, 404-415.

McGowan J.G., 1990 Large scale solar/wind electrical production systems-predictions for the 21st century, Massachusetts: MIT.

Mirasgedis, S., Sarafidis, Y., Georgopoulou, E., Kotroni, V., Lagouvardos, K., Lalas, D.P., 2007 Modeling framework for estimating impacts of climate change on electricity demand ar regional level: Case of Greece, Energy Conversion and Management 48: 1737-1750.

Mitchell, C., Bacuknecht D., Connor, P.M., 2006 Effectiveness through risk reduction: a comparison of the renewable obligation in England and Wales and the feed-in system in Germany, Energy Policy 34:(3), 297-305.

Moran, M.J., Sciubba, E., 1994 Exergy analysis: Principles and practice, Journal of Engineering for Gas Turbine and Power, 116, 285-290.

Morris, D.R., Steward, F.R., Szargut, J., 1988 Exergy analysis of thermal, Chemical and metallurgical Processes, Hemisphere, New York.

NASA Langley Research Center, 2005 Earth's Energy Budget, Students' Cloud Observations On-Line Project, asd-www.larc.nasa.gov/SCOOL/budget.gif.

Natural Gas Fact's website, 2009 www.naturalgas.com

Ouranos, 2004 In: DesJarlais, C., Bourque, A., Decoste, R., Demers, C., Deschamp, P., Lam, K-H.(Eds), Adapting to climate change, Ouranos, Montreal, ISBN2-923292-01-4.

Peat Marwick Stevenson & Kellogg (PMSK) in association with Marbek Resource Consultants, Torrie Smith and Associates, 1991 The economically attractive potential for energy efficiency gains in Canada, WATSRF, May.

Pitts, C.A., Smith, P., 1997 Concepts in Practice - Energy, Building for the third millennium, Batsford, Britain.

Plug into Green Canada's website, 2009 www.plugintogreencanada.com

Rec Group's website, 2009 www.recsolar.com

Regles ThG. Cahiers du CSTB 2256, Paris 1988. Regles ThBV. de calcul du coefficient de besoins de chauffage des logements.Cahiers du CSTB 2258, Paris 1988; Regles ThBV. de calc deul du coefficient de chauffage des logements, Annexes. Cahiers du CSTB 2274, Paris 1988; Regles ThC. de calcul du coefficient de performance thermique globale des logements. Cahiers du CSTB 2259, Paris; Regles ThC. de calcul du coefficient de performance thermique globale des lodgements. Complements et annexes. Cahiers du CSTB 2275, Paris.

Reistad, G.M., 1970 Availability: concepts and applications, Ph.D. Dissertation, University of Wisconsin, Madison.

Renaud, G., Zmeureanu, R., 2008 Estimation of potential impact of climate change on the heating energy use of existing houses, In Energy Policy 36: 303-310.

Renewable Energy UK's website, 2009 www.reuk.co.uk

RETScreen, ground source heat pump project chapter, 2009 www.retscreen.com

Rogers, J.C., Simmons, E.A., Convery, I., Weatherall, A., 2008 Public perceptions of opportunities for community-based renewable energy projects 36: (8) 4217-4226.

Santamouris, M., 1995 Energy retrofits of office buildings, CIENE, University of Athens.

Santomouris, M., 2005 Energy performance of residential buildings: A practical guide for energy rating and efficiency, UK and USA.

Schweizer-Ries, P., Wemheuer, C., Zoellner, J., 2008 Public acceptance of renewable energies: Results from case studies in Germany, Energy Policy 36: 4136-4141.

Sciubba, E., 1999. Exergy as a direct measure of environmental impact, In: Aceves, S.M., et al. (Eds), Proceeding of ASME advanced Energy system Division, AES-vol. 39, pp. 573-581.

SIA 180/4, 1995, Die Energiekennzahl -L'indice de depense d'energie.SIA Postfach, 8039 Zurich.

Sinclair, P., Lofstedt, R., 2001 The influence of trust in a biomass plant application: the case study of Sutton, UK, Biomass and Bioenergy 21: (3), 177-184.

Solar Panel info's website, 2009, www.solarpanelinfo.com.

Spreng, D., 2005 Distribution of energy consumption and the 2000 W/capita target (viewpoint), Energy Policy 33: 1905-1911.

Steg, L., 2008 Promoting household energy conservation, Energy Policy 36: 4149-4453.

Steger, U., Achterberg, W., Block, K., Bode, H., Frenz, W., Gather, C., Hanekamp, G., Imboden, D., Jahnke, M., Kost, M,. Kurz, R., Nutzinger, H.G., Ziesmer, T., 2002. Nachhaltige Entwicklung und Innovation im Eneriebereich, (An English translation with the title "Sustainable Development and Innovation inthe Energy Sector" by the same authors and publisher has been published in 2005) Springer Berlin Heidelberg (Chapter 4.2 and 4.3)

Strong, M.F., 1992 Energy, environment and development, Energy Policy 20: 490-4.

Swiss Federal Council, 2002 Sustainable development strategy 2002, Bern.

Szargut, J., 1980 International process in second law analysis, Energy 5, 709-718.

Thatcher, M., 2006 Modeling changes to electricity demand load duration curves as a consequence of predicted climate change for Australia, Energy 32: 1647-1659.

Toke, D., 2005 Explaining wind power planning outcomes: some findings from a study in England and Wales, Energy Policy 33: (12), 1527-1539.

Upham, P., Shackley, S., 2006 The case study of a proposed 21.5 MW(e) biomass gasifier in Winkleigh, Devon: implications for governance of renewable energy planning, Energy Policy 34: (15), 2161-2172.

Upham, P., Shackley, S., 2007 Local public opinion of proposed 21.5 MW(e) biomass gasifier in Devon: questionnaire survey results, Biomass and Bioenergy 31: (6), 433-441.

Upreti, B.R., 2004 Conflict over biomass energy development in the United Kingdom: some observations and lessons from England and Wales, Energy Policy 32: (6), 785-800.

Visual Dictionary Online Website, 2009 www.visualdictionaryonline.com

Wikipedia, Online Encyclopaedia, 2009 www.Wikipedia.com

WSE Technology's Website, 2009 www.wsetech.com

Wu, Y., Zhao, J., Zhu, N., 2008 Check and evaluation system on heat metering and energy efficiency retrofit of existing residential buildings in northern heating areas of china based on multi-index comprehensive evaluation method, Energy Policy (in press).

Yang, M., 2008 China's efficiency target 2010, Energy Policy 36: 561-570.

Yannas, S., 1994 Energy and housing design-Volume I, Principles, Objectives, Guidelines, Architectural Association, London.

Young, D., 2008 When do energy efficient appliances generate energy saving? Some evidence from Canada, Energy Policy 36: 34-46.

Zephyr Power's website, 2009 www.zephyrpower.com

Zmeureanu, R., 1990 Assessment of the energy saving due to the building retrofit. Building and Environment 25: (2), 95-103.

Zmeureanu, R., 1992 A new method for evaluating the normalized energy consumption in office buildings, Energy 17: (3), 235-246.

Zografaski, N., 2000 Technologies for rational use and saving of energy in building, Energy 62: 112-114.